



TFAWS 2015

Thermal Coatings Seminar Series Training Part 2 : Environmental Effects

NASA GSFC Contamination and Coatings Branch – Code 546

Hosted by: Jack Triolo - SGT, Inc.

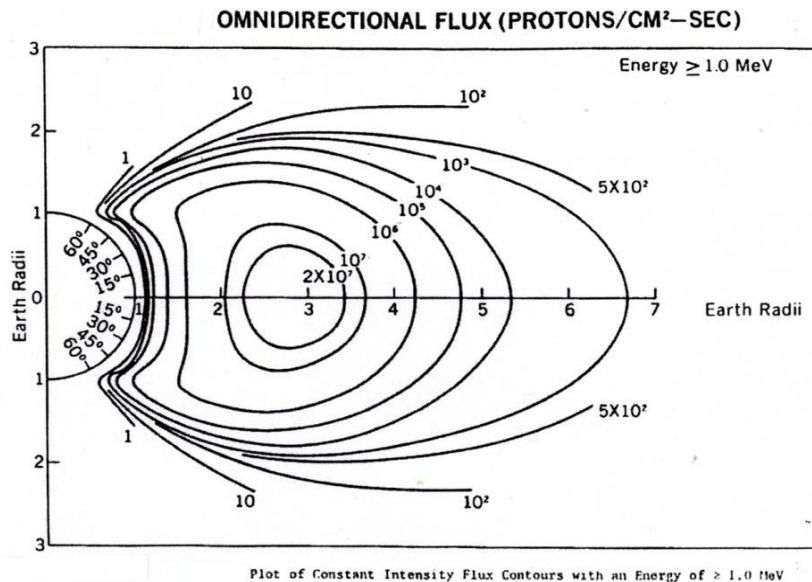


Agenda

- Orbital Environments versus Orbital Altitude
- Tests for Environmental Effects on Coatings
- Orbital In-flight Test Descriptions
- Orbital In-flight Test Results versus Orbital Altitude
- In-flight Results versus Laboratory Test Results
- Atomic Oxygen In-flight Tests and Results
- Returned Flight Hardware
- Coating Issues

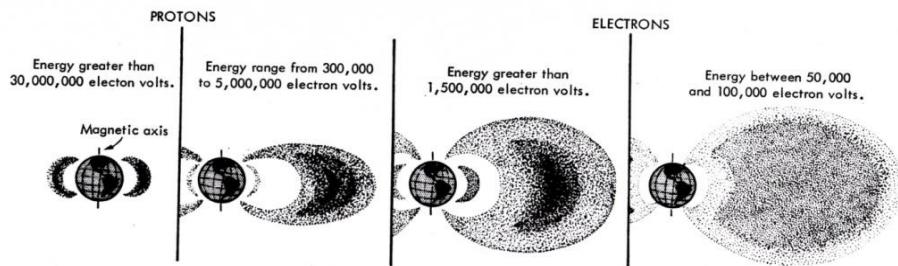


CHARGED PARTICLE ENVIRONMENTS



Earth Radius=6,300 km (4,000 mi)

THE VAN ALLEN BELTS SEEN IN CROSS SECTION IN TERMS OF FOUR TYPES OF PARTICLES



Van Allen radiation belts, as detected by rocket and satellite shots. Because the earth's magnetism weakens with distance, the most energetic protons (left) are trapped nearest the earth. Low-energy electrons (right) are evenly distributed over magnetosphere. (Adapted from the New York Times, April 11, 1962.)



Induced Environments

- All Orbits
 - Direct view of contamination source to sensitive surface combined with UV, CP, AO.
- LEO
 - Ambient return flux in ram (velocity) direction. Outgassing molecules colliding with ambient atmosphere and returning to spacecraft surface.
- MEO/GEO
 - Electrostatic Return (ESR). Molecule ionized by UV and attracted back to charged s/c surface
- Space Debris
 - Anything from paint flacks to nuts, bolts, and tools.



Orbital Altitudes

- LEO -- <1000km ---- UV, AO, Low Flux Charged Particles (CP)
- GEO -- 35,786km ---- UV, High Flux CP
- MEO -- >1000km to 25,000km ---- UB, Very High Flux CP
- L1, L2, Lunar ---- UV, Solar Wind (Low Energy Protons + Electrons)
- Elliptical ---- All of the above but lower fluxes



How do we Test for Environmental Effects?



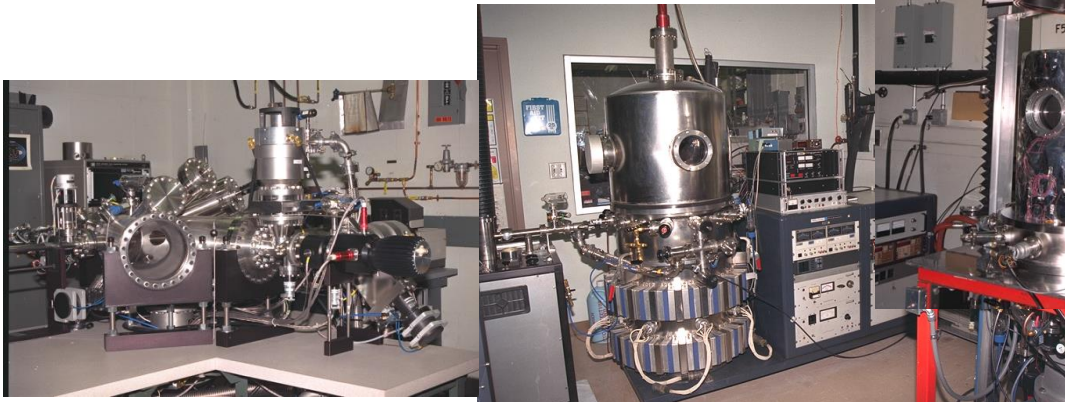
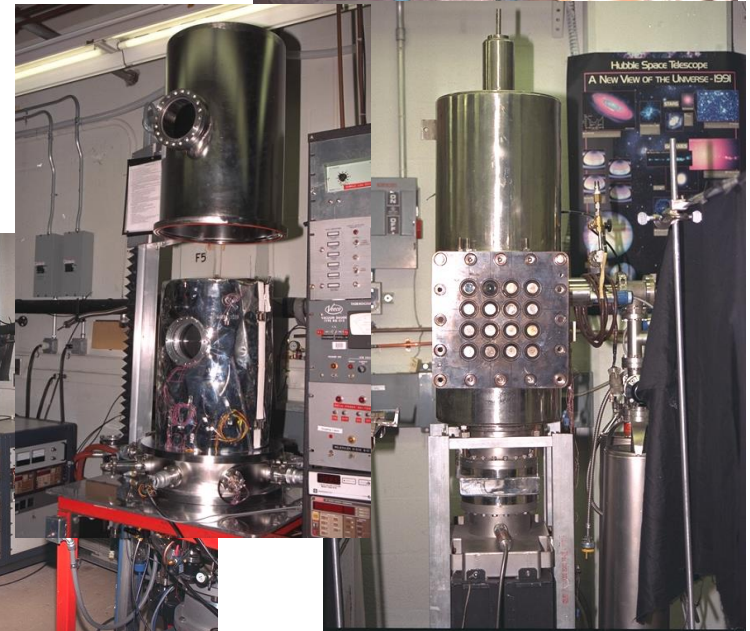
- Laboratory Testing (measured in-situ or ex-situ)
 - Vacuum UV (1216 Å to 1800 Å)
 - UV (1800 Å to 4000 Å)
 - Charged Particles – electrons and protons tested to adsorbed energy – Rads (material specific) with mono energetic electrons and protons, which can be combined or separate and with or without UV
 - Atomic Oxygen – with or without UV
 - All of the above + intentionally introduced molecular contaminants



NASA-GSFC Coatings Space Environmental Test Facilities



- Calorimetric Emittance Facility
- Multisides “UV” Degradation Chamber
- Solar Wind Facility
- Electrostatic Charge Facility
- Thermal Cycling Chambers
- Various Vacuum Chambers



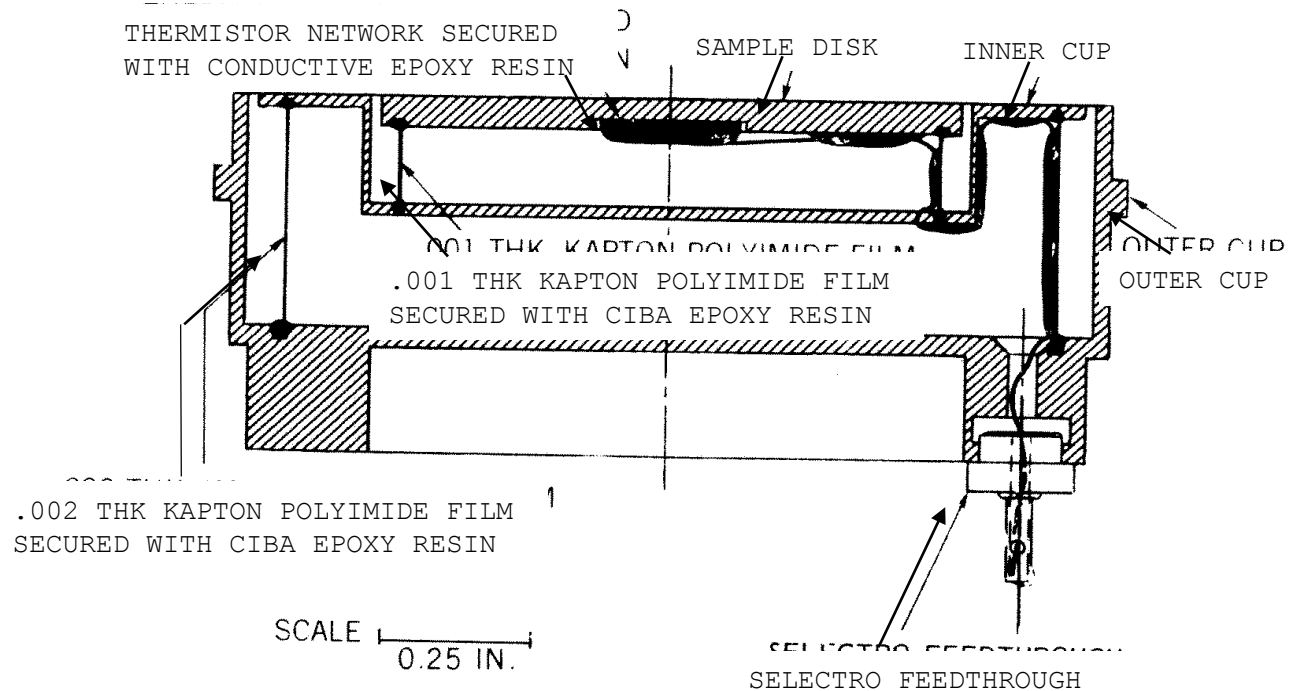


On-Orbit In-Flight Testing

- LEO
 - OSO-8
- GEO
 - ATS-1, ATS-2, ATS-3, SCATHA (P87-2)
- MEO
 - NTS-2
- 35 Earth Radii
 - IMP-8
- CMP
 - LDEF, STS-8 (GAS-CMP), STS-11 (GAS-CMP), EOIM-3



COATINGS CALORIMETER



Sensor Cup Design

Calorimeter design with inner cup and sample disk having the same area



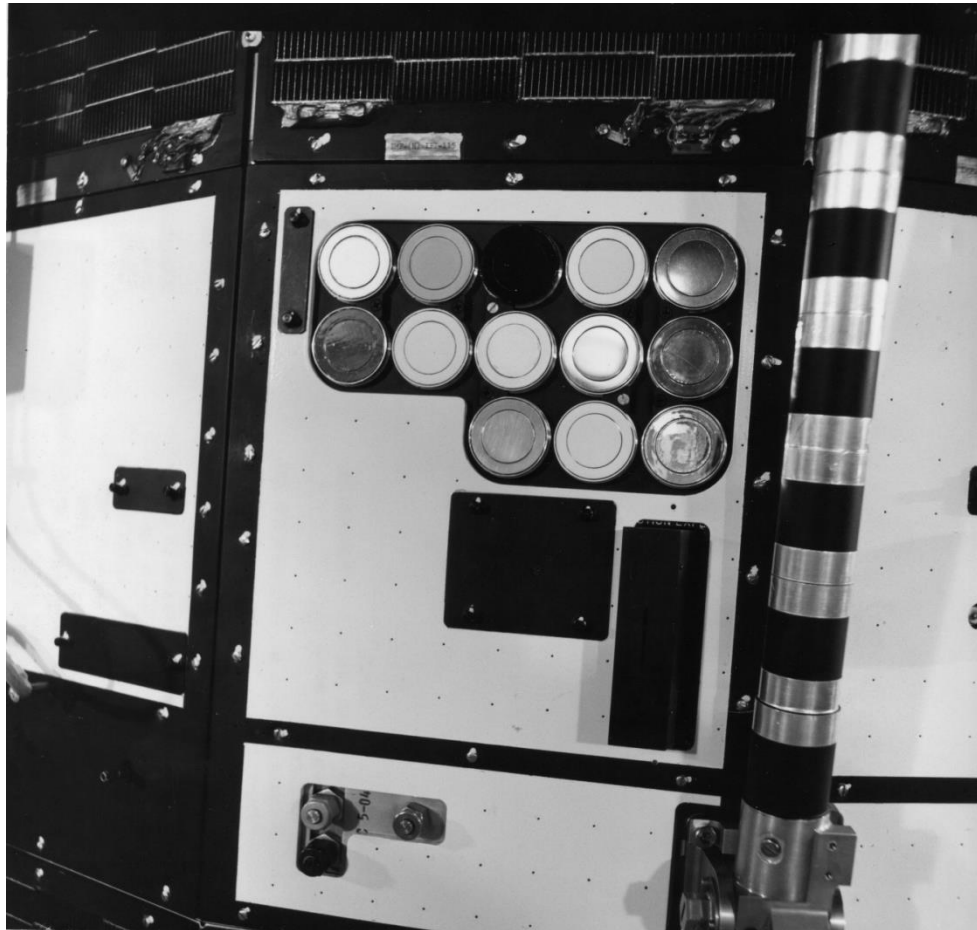
AST-2



ATS-2 Coatings
Experiment
GEO orbit



OSO-8



OSO-8 Coatings
Experiment intergraded
into the S/C



OSO-8



OSO-8 Coatings Experiment LEO orbit





Comparison of Flight Data for Various Orbits

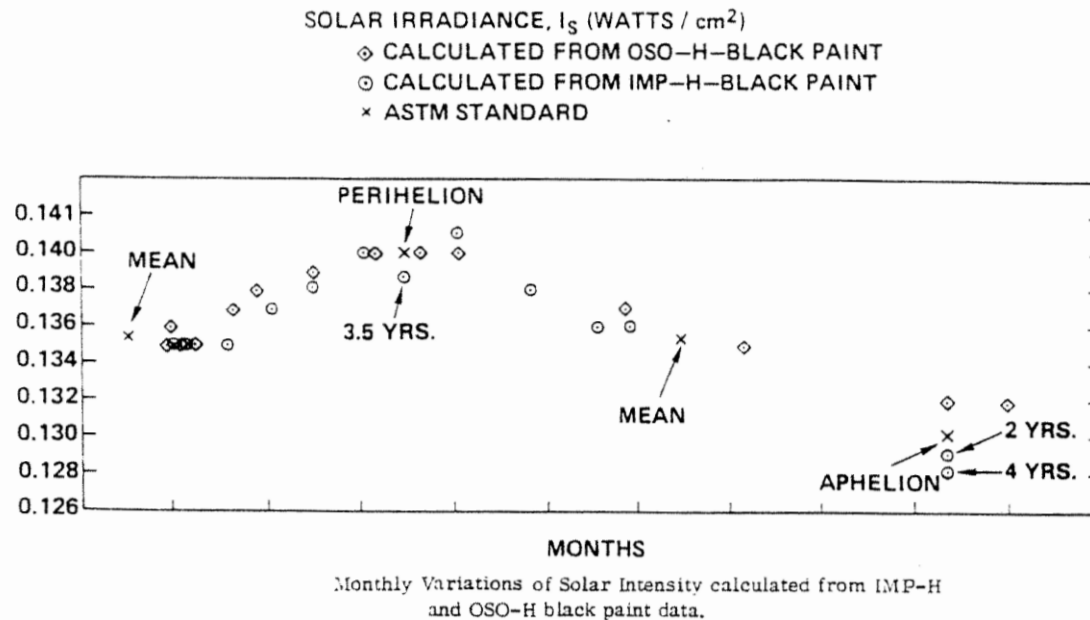
COATING	LEO (OSO-8) 348X203 miles	MEO (NTS-2) 10,000 miles	GEO (ATS-1 & SCATHA)	EX-GEO (IMP-8) 136,000 miles
	Delta a/3yrs	Delta a /month	Delta a /3yrs	Delta a /3yrs
AL/SiOx	0.0		0.10	0.05
CC/AL	0.0	0.02 /month	0.05	0.03
MS-74	0.0		0.34	0.13
Ag FEP	0.01	0.012 /month	0.08	0.06
Al FEP	0.02			0.04
NS43C/G		0.023 /month	0.09	
OSR		0.01 /month	0.02 (0.04/10yrs)	
Kapton			0.10	0.14

MEO has the highest degradation rate

LEO has the lowest degradation rate



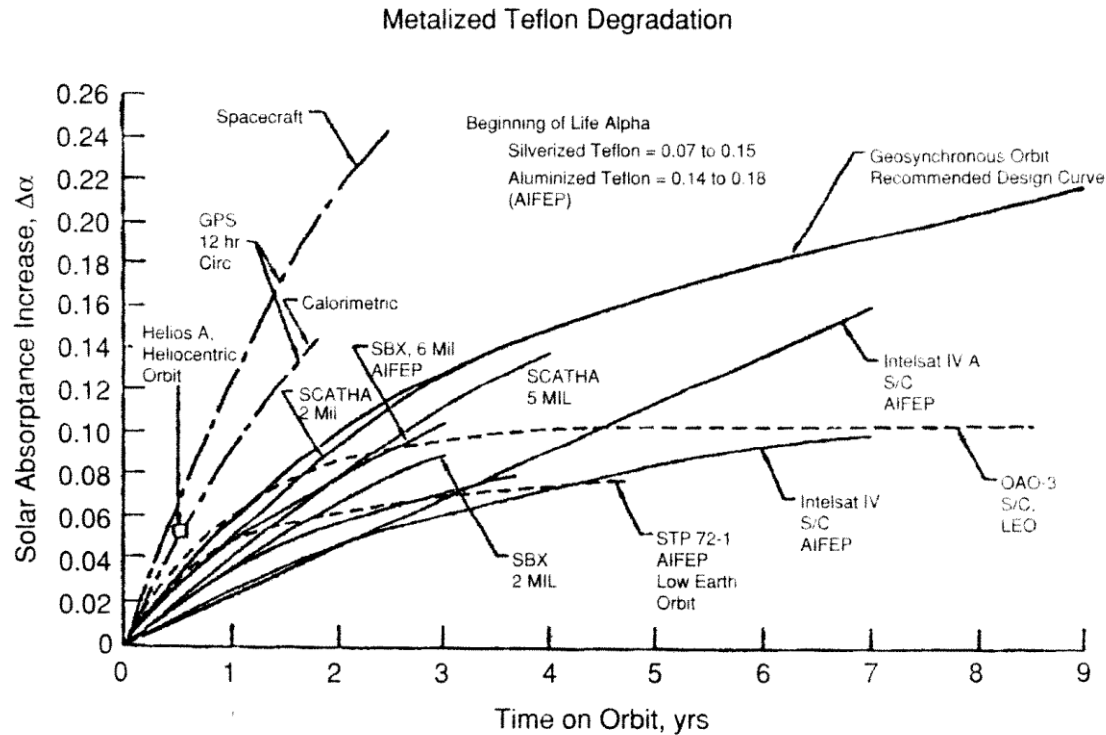
COATINGS EXPERIMENT BLACK MONITOR



Black paint shows effect of bleaching with UV exposure



TEFLON FLIGHT DATA

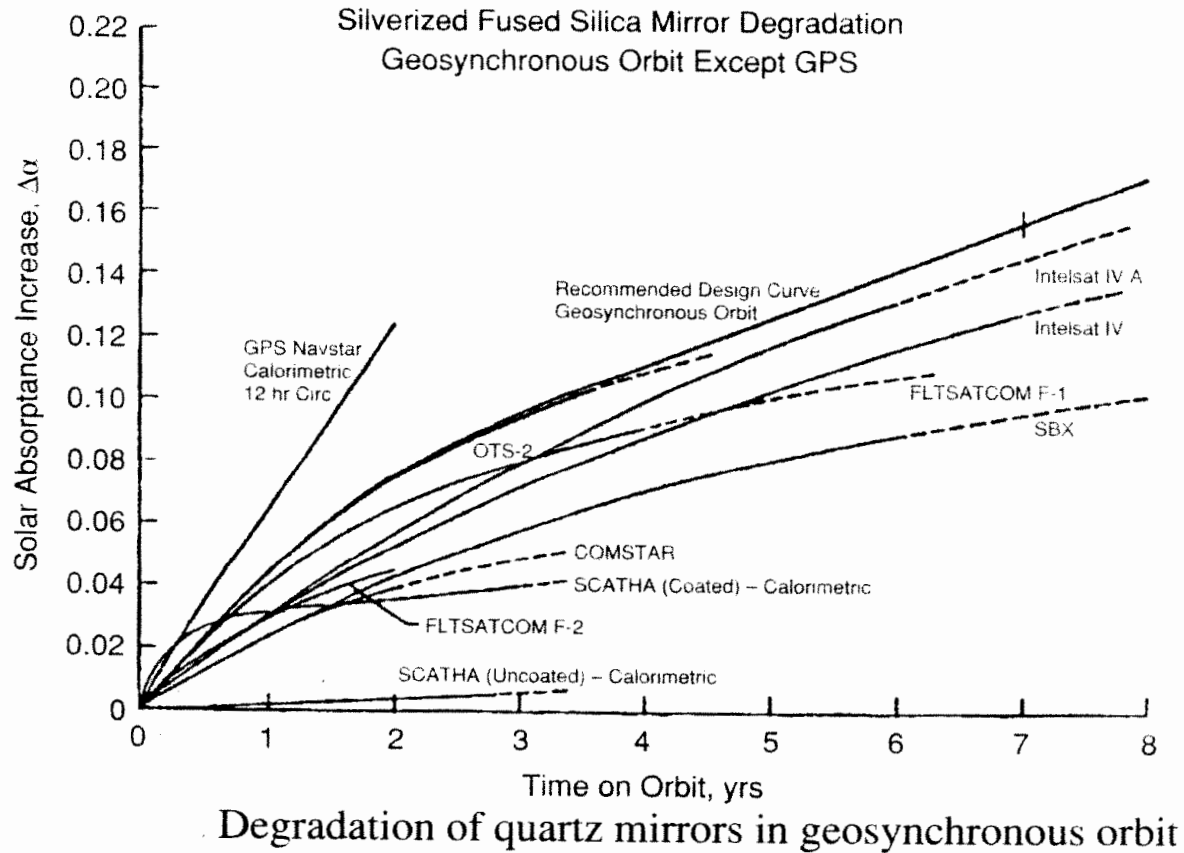


Metalized Teflon degradation (in geosynchronous orbit unless
otherwise indicated)

Solar absorptance changes orbit and s/c cleanliness dependence



OSR FLIGHT DATA



Same orbital and s/c cleanliness dependence

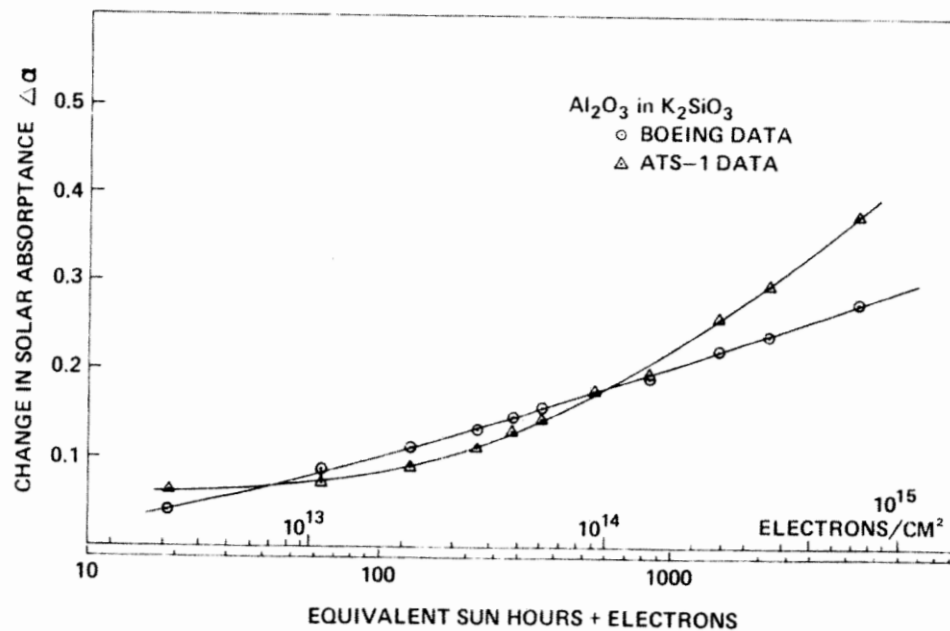


Comparisons Between In-Flight and Laboratory Testing





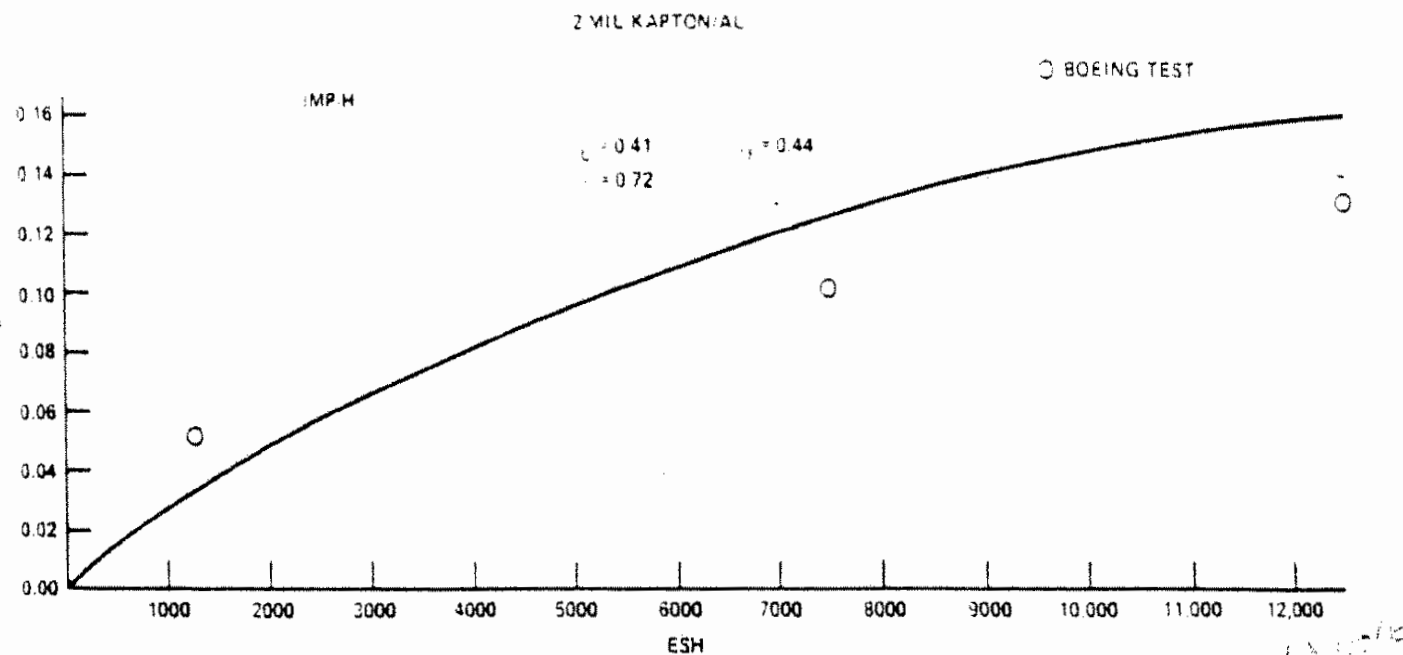
ATS-1 / LABORATORY COMPARISON



$\Delta\alpha$ as a Function of Solar and Electron Irradiation
and Comparison With ATS-1 Data for Al₂O₃/K₂SiO₃



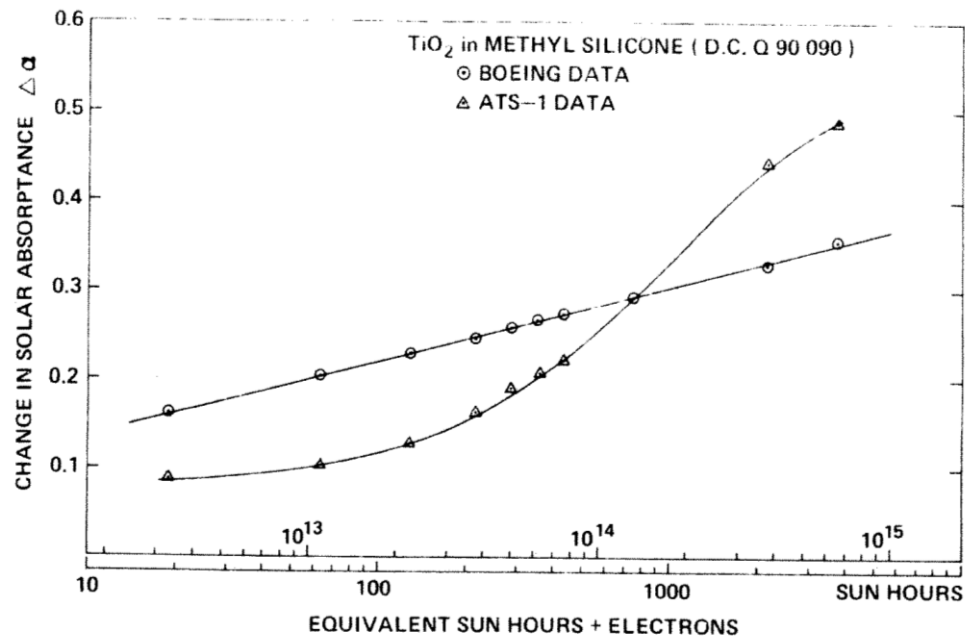
IMP-8 / LABORATORY COMPARISON



$\Delta\alpha$ of 2 mil Kapton/Al as a function of Orbital exposure—from IMP-H,
compared with Boeing laboratory test data.



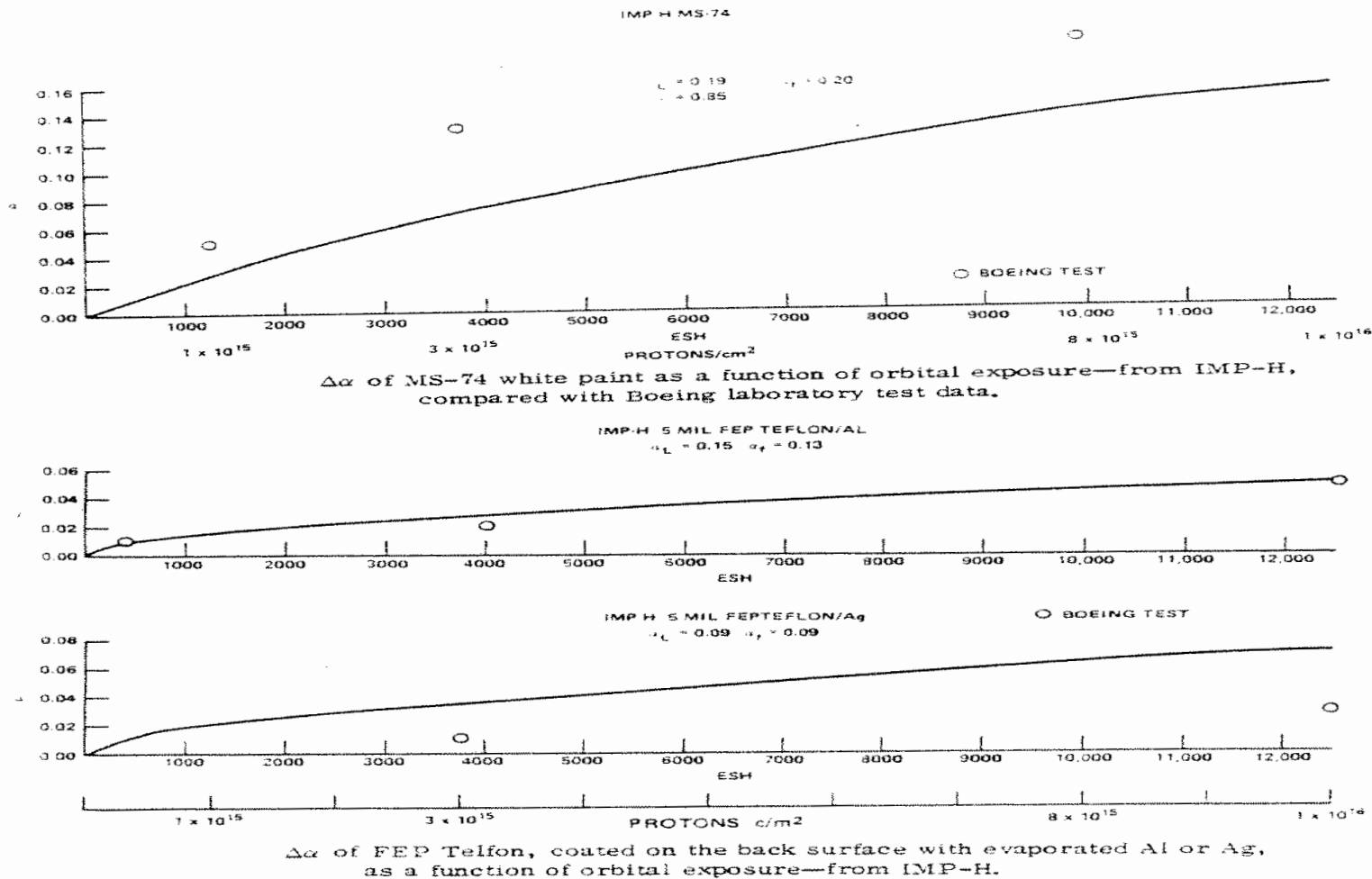
ATS-1 / LABORATORY COMPARISON



$\Delta\alpha$ as a Function of Solar and Electron Irradiation
and Comparison With ATS-1 Data for Dow Corning Q90-090



IMP-8 / LABORATORY COMPARISON

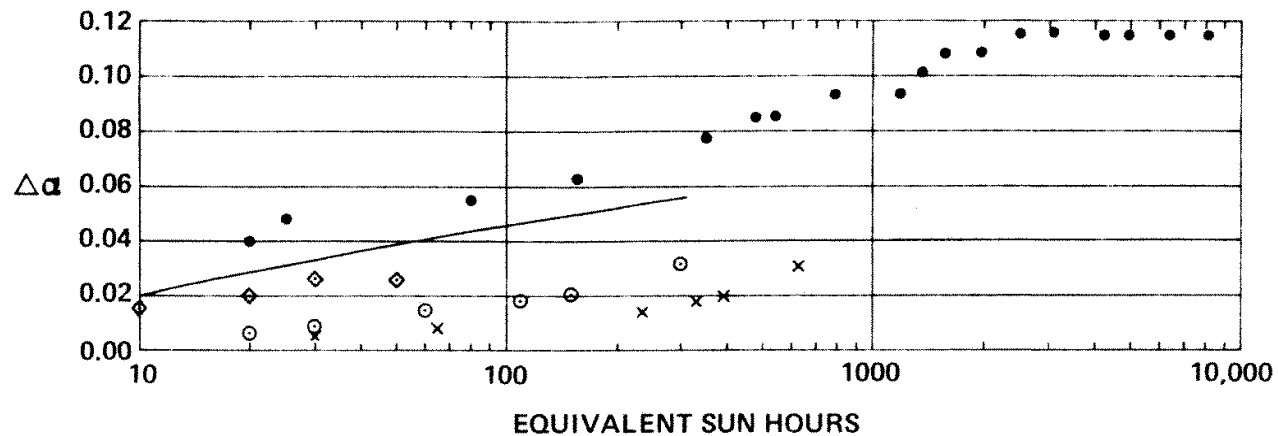




FLIGHT VERSUS LABORATORY

ALZAK

- 1 X SPECTOL AB X-25 SOLAR SIMULATOR (FILTERED α) REAL TIME
- 2 \diamond MICROWAVE RESONANCE LAMP (185 -- 206nm)
- 3 \odot X-25 SAME AS (1) BUT TIME SCALED WITH ATS - III SHIELDED DATA
- 4 — ESTIMATED FROM (2) & (3)
- 5 ● OSO-H THERMAL CONTROL COATINGS MONITOR



$\Delta\alpha$ of Alzak "Control" - Comparison of Laboratory and In-flight Test Data

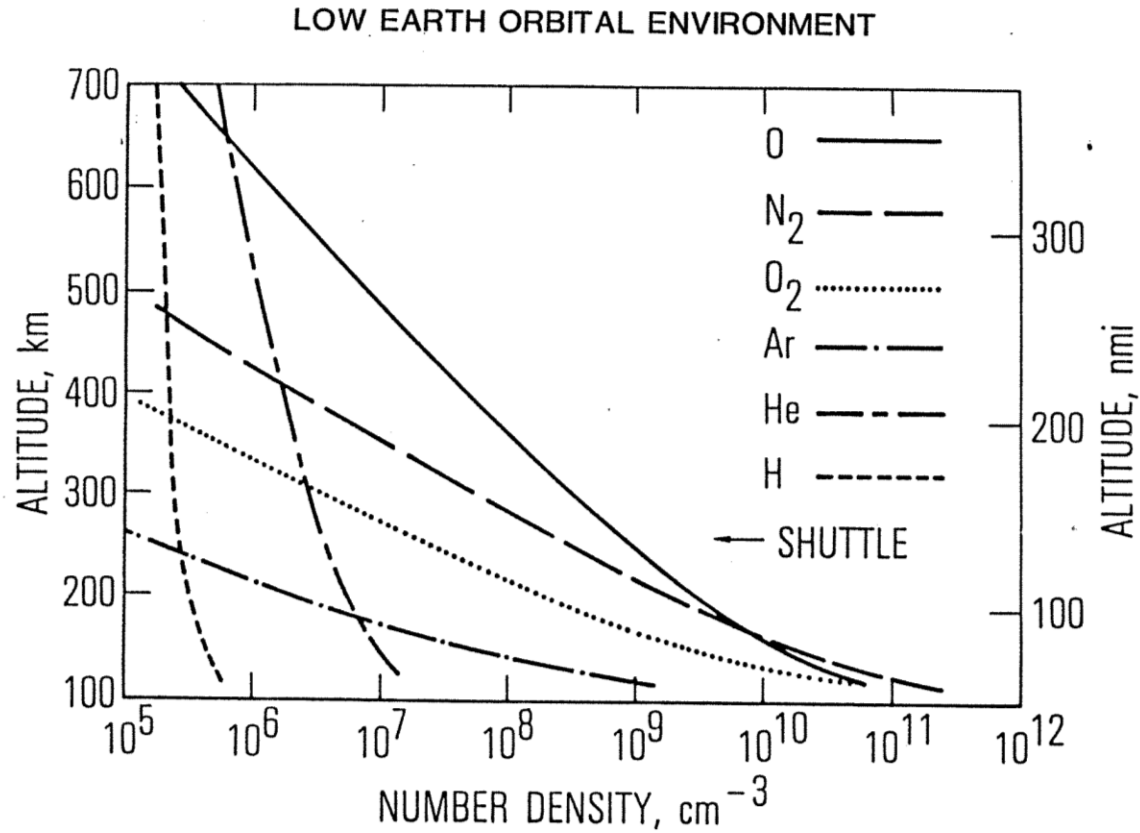


Atomic Oxygen Effects

- What affects AO flux?
 - Altitude
 - Solar Cycle
 - Ram Direction
- In-Flight Results
- Reaction Rates for Various Materials



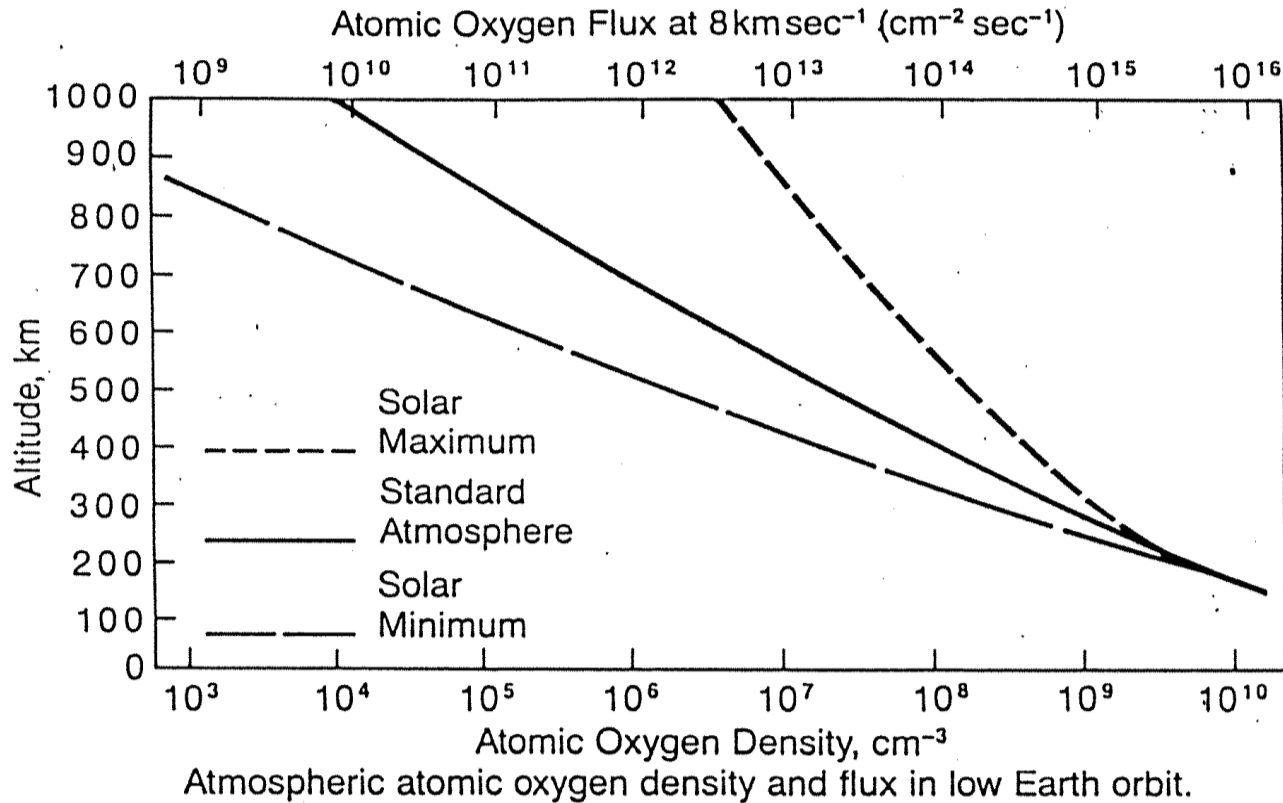
ATOMIC OXYGEN



TEXT



ATOMIC OXYGEN

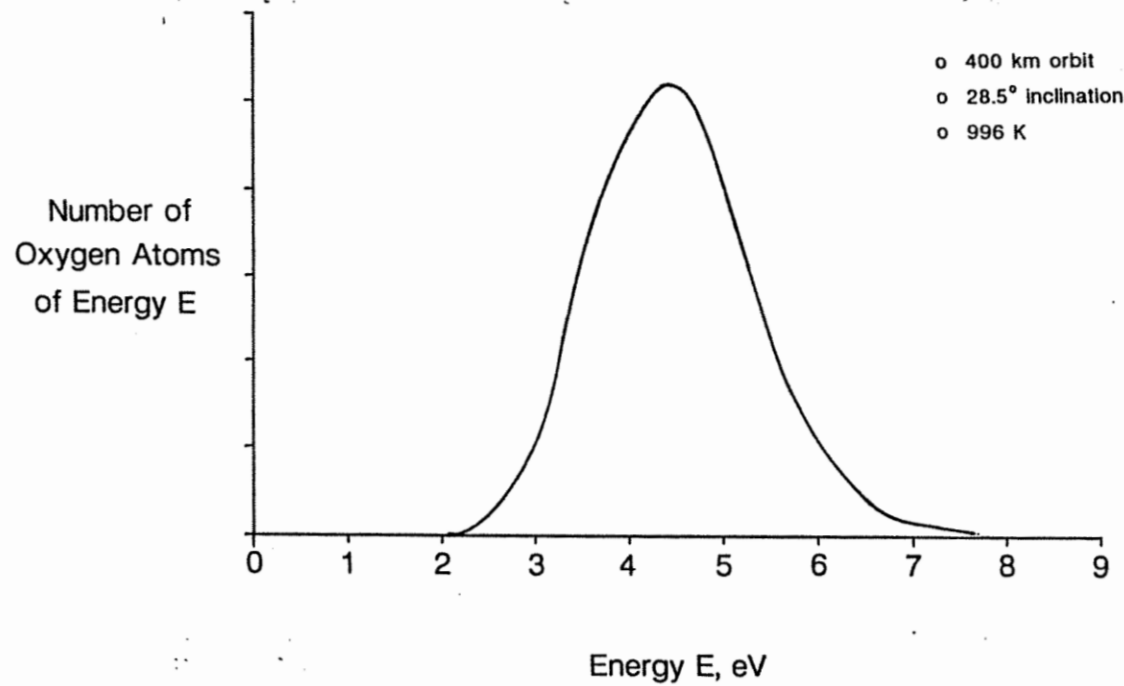


Large range of flux between solar max and min



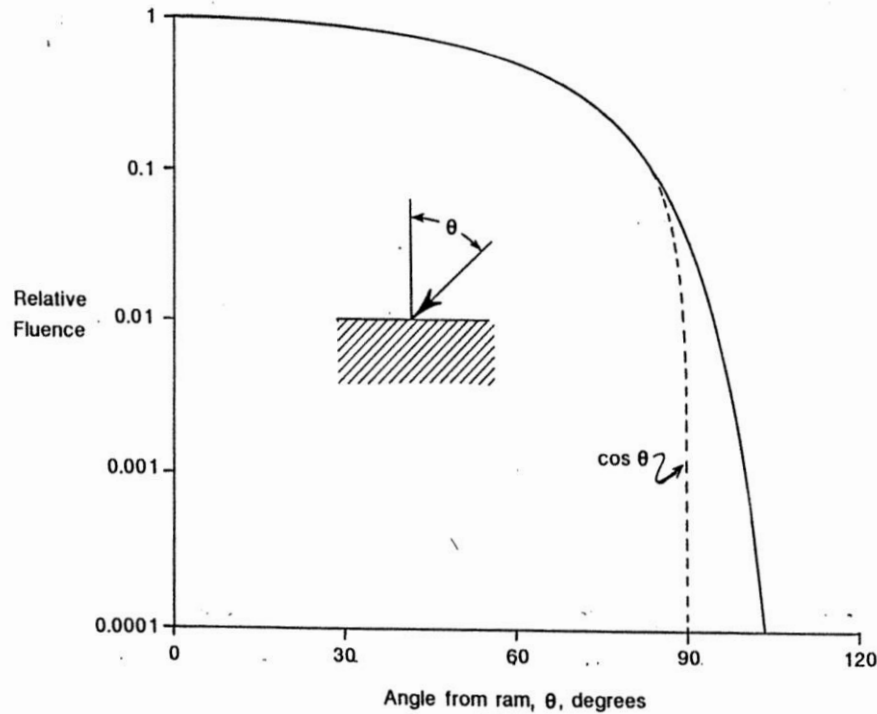
ATOMIC OXYGEN

LOW EARTH ORBITAL ATOMIC OXYGEN ENERGY DISTRIBUTION



ATOMIC OXYGEN

ATOMIC OXYGEN FLUENCE DEPENDENCE ON ARRIVAL ANGLE



Slight spread effects past 90 degrees



On-Orbit In-Flight Testing

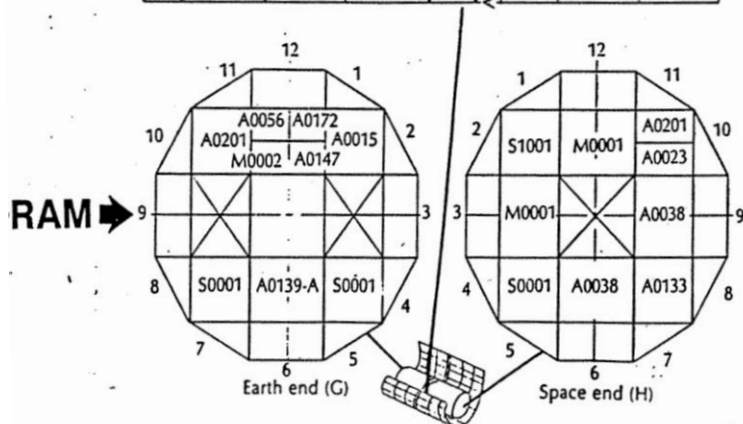
- LEO - OSO-8
- GEO - ATS-1, ATS-2, ATS-3, SCATHA (P87-2)
- MEO - NTS-2
- 35 Earth Radii - IMP-8
- EMP
 - LDEF (Long Duration Exposure Facility), STS-8 (GAS-CMP), STS-11 (GAS-CMP), STS-13-EOIM 3



LDEF

Bay Row	A	B	C	D	E	F
1	A0175	S0001	Grapple	A0178	S0001	S0001
2	A0178	S0001	A0015 A0187 M0006	A0189 A0172	S0001	A0178 P0004 P0006
3	A0187	A0138	A0023 A0034 A0114 A0201	M0003 M0002	A0187 S1002	S0001
4	A0178	A0054	S0001	M0003	S0001	A0178
5	S0001	A0178	A0178	A0178	S0050 A0044 A0135	S0001
6	S0001	S0001	A0178	A0201 S0001	A0023 S1006 S1003 M0002	A0038
7	A0175	A0178	S0001	A0178	S0001	S0001
8	A0171	S0001	A0056 A0147	M0003	A0187	M0004
9	S0069	S0010	A0134 A0023 A0034 A0114 A0201	M0003 M0002	S0014	A0076
10	A0178	S1005	Grapple	A0054	A0178	S0001
11	A0187	S0001	A0178	A0178	S0001	S0001
12	S0001	A0201	S0109	A0023 A0019 A0180	A0038	S1001

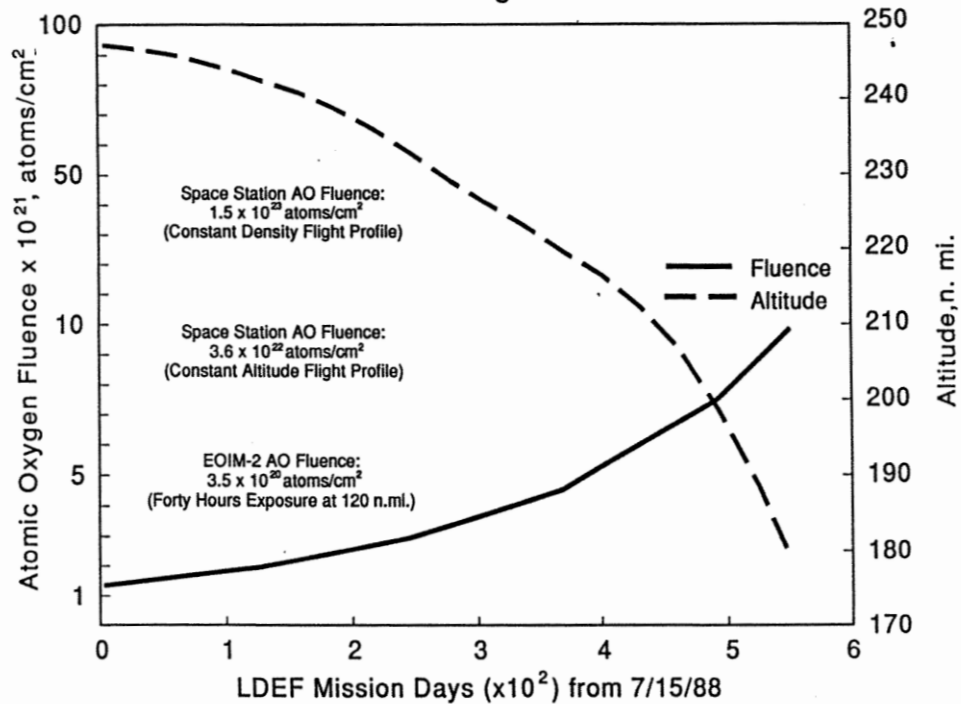
Samples located around the surface provided every angle of attack including the wake





LDEF

LDEF (Long Duration Exposure Facility) Atomic Oxygen Fluence on Forward-Facing Surfaces



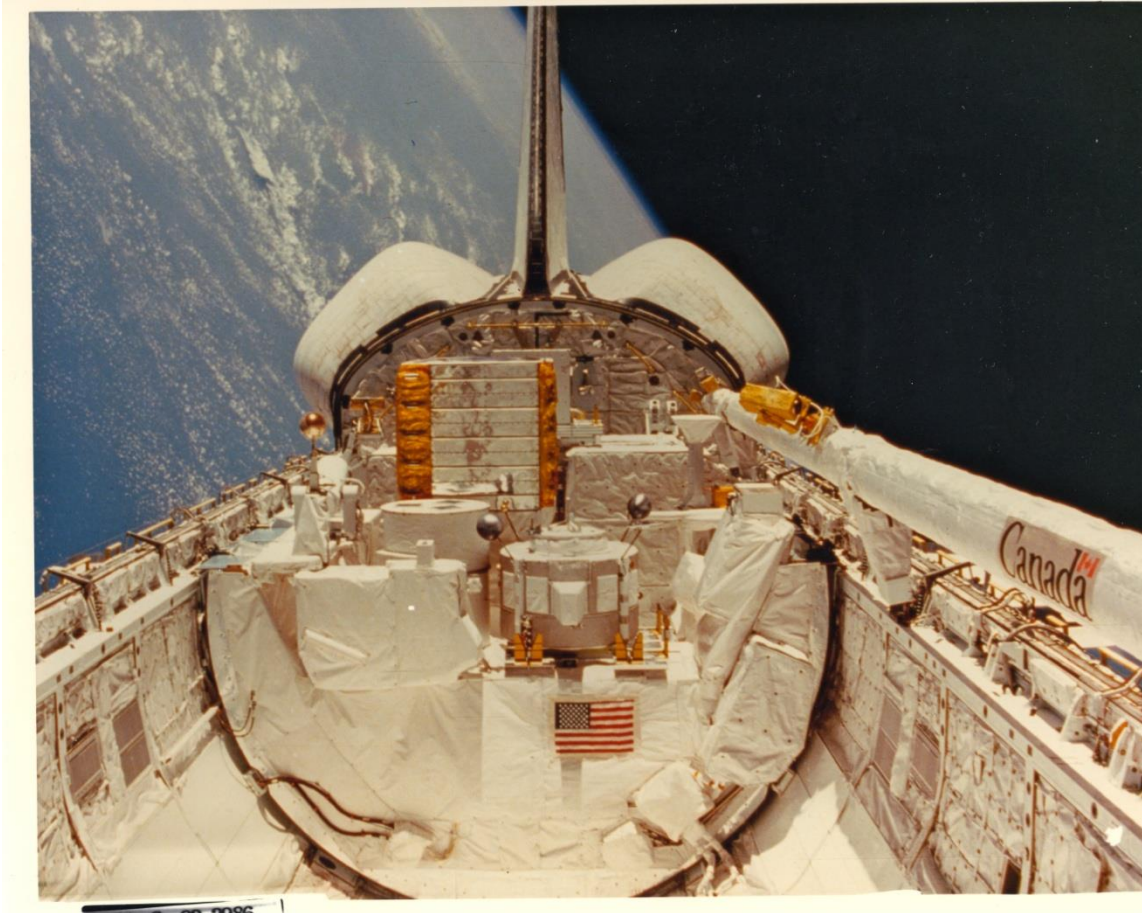
J.T. Visentine
NASA/JSC, ES5

Release Date: 2/1/90
X000059Z

Delayed recovery made for more interesting results



STS-3



STS-3 Cargo Bay
GSFC Contamination Monitor Package (CMP)



STS-8



First time AO material erosion test vs
time
Package design to STS-8 delivery was
56 days!

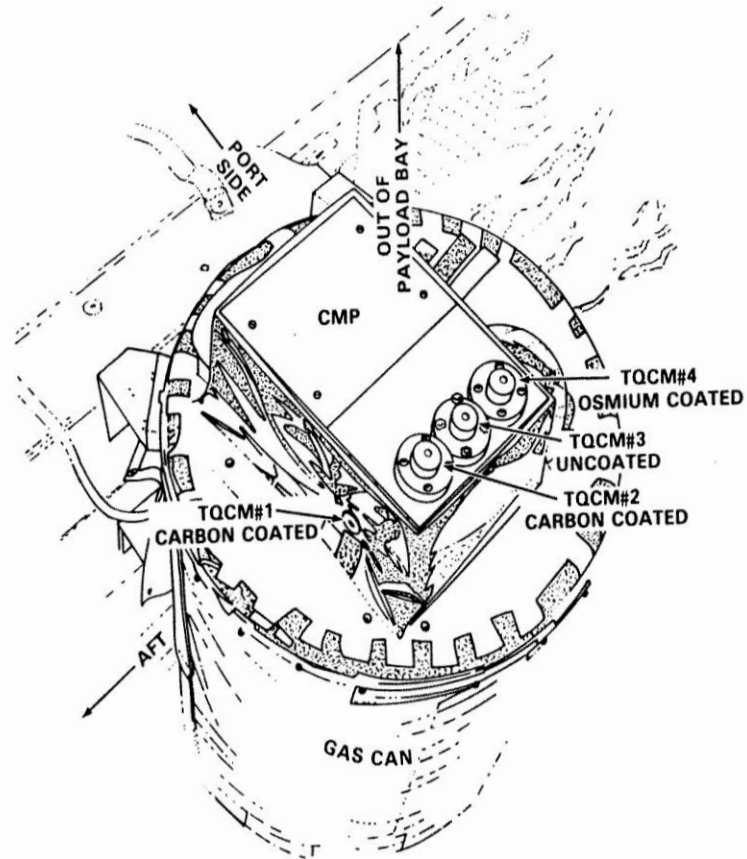


FIGURE 1
CMP CONFIGURATION, STS-8



STS-8

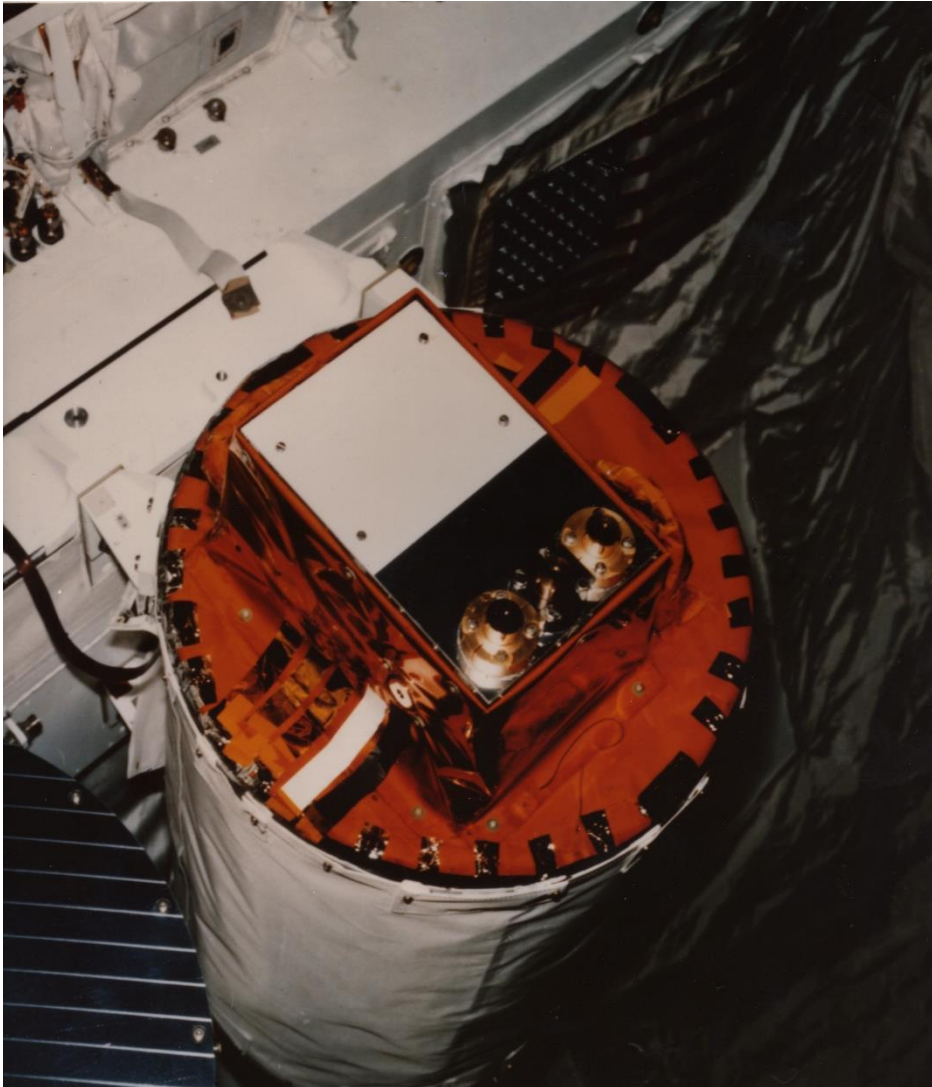


Pre-flight inspection





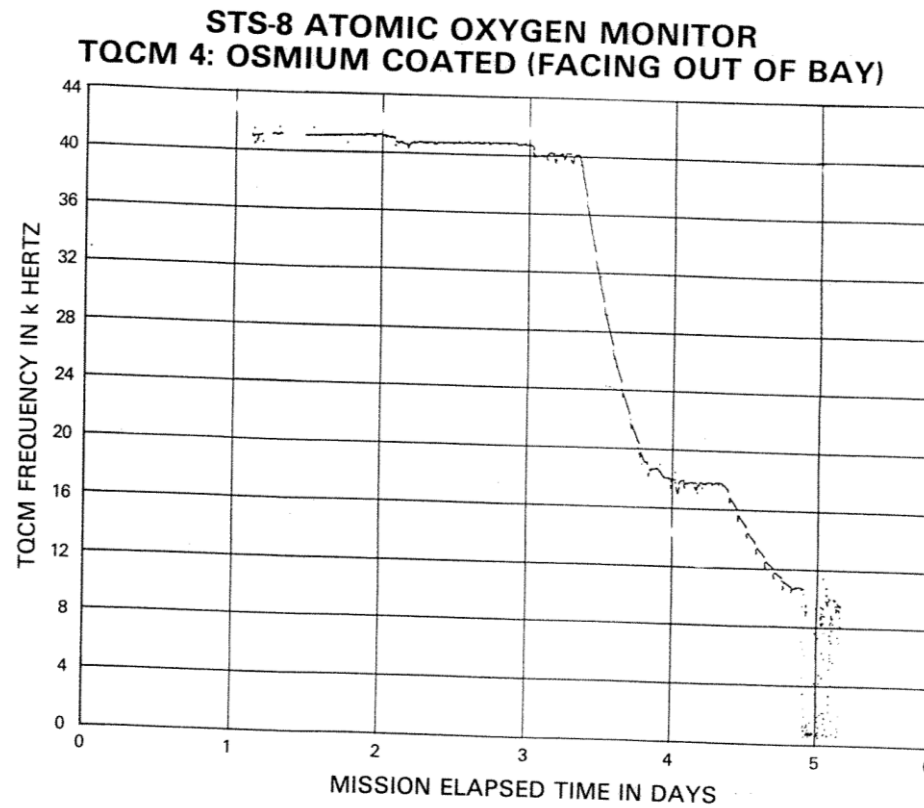
STS-8



Post flight shows both eroded and non-eroded Kapton surfaces



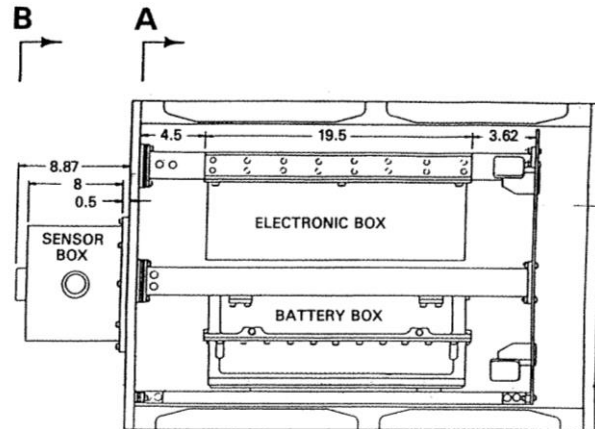
STS-8



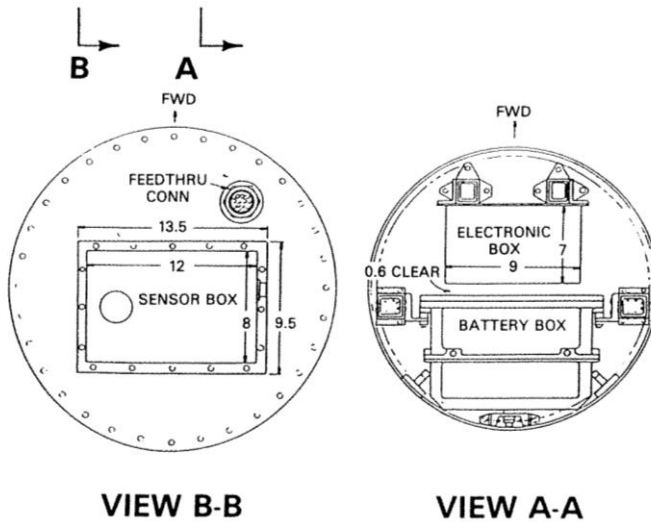
Can you guess STS-8 was bay-to-ram?



STS-8



What is inside the GAS can?

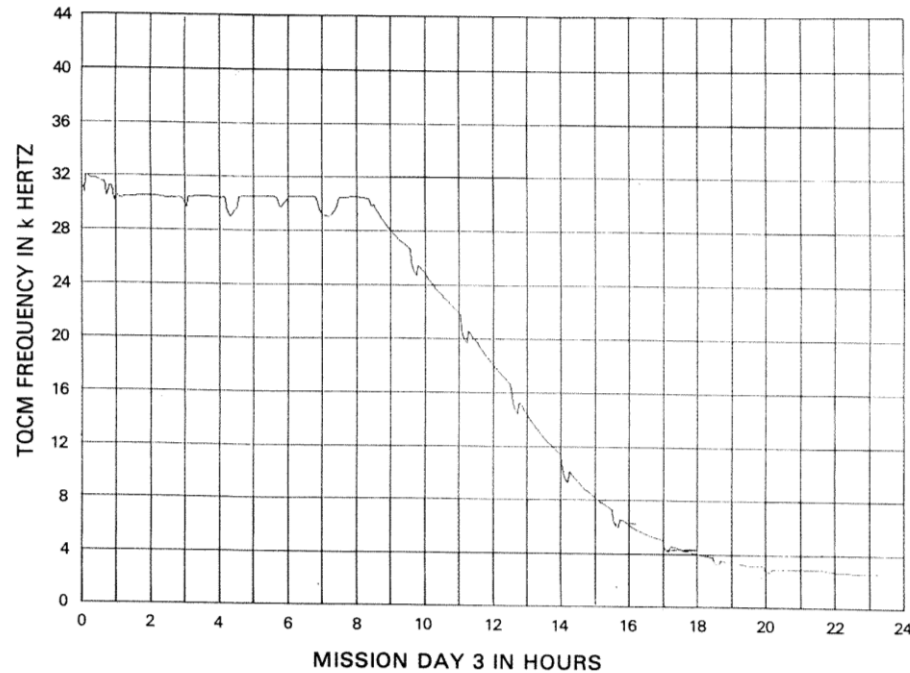




STS-8



**STS-8 ATOMIC OXYGEN MONITOR
TQCM 2: CARBON COATED (FACING OUT OF BAY)
DAY 3**



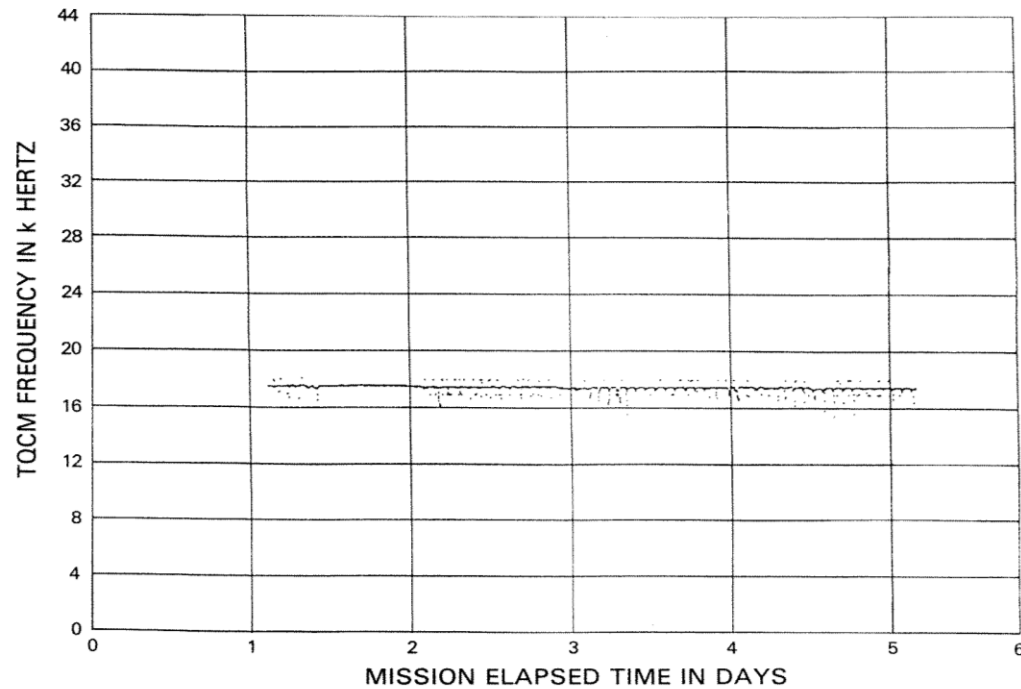
Notches in data are artifices of QCM solar effects



STS-8



STS-8 ATOMIC OXYGEN MONITOR TQCM 1: CARBON COATED (FACING AFT)



QCM not in ram



CONTAMINATION MONITORING PACKAGE

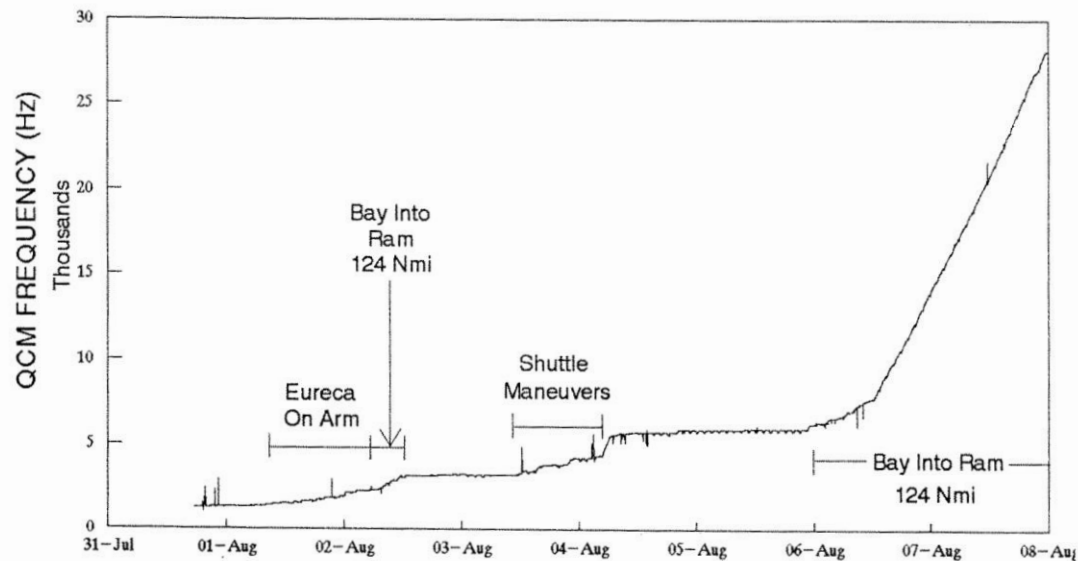
Quartz Crystal Microbalances

- 15 megahertz TQCM's manufactured by Faraday
- TQCM's were maintained at 30° throughout mission to prevent contaminant build-up on crystals.
- TQCM Coatings:
 1. Carbon
 2. Kapton
 3. Teflon
 4. Polyurethane
 5. Uncoated (control sample)



EIOM₃ /EMP

TQCM #5 Flight Data - Uncoated



QCM measures increased mass in ram





EOIM₃ RESULTS

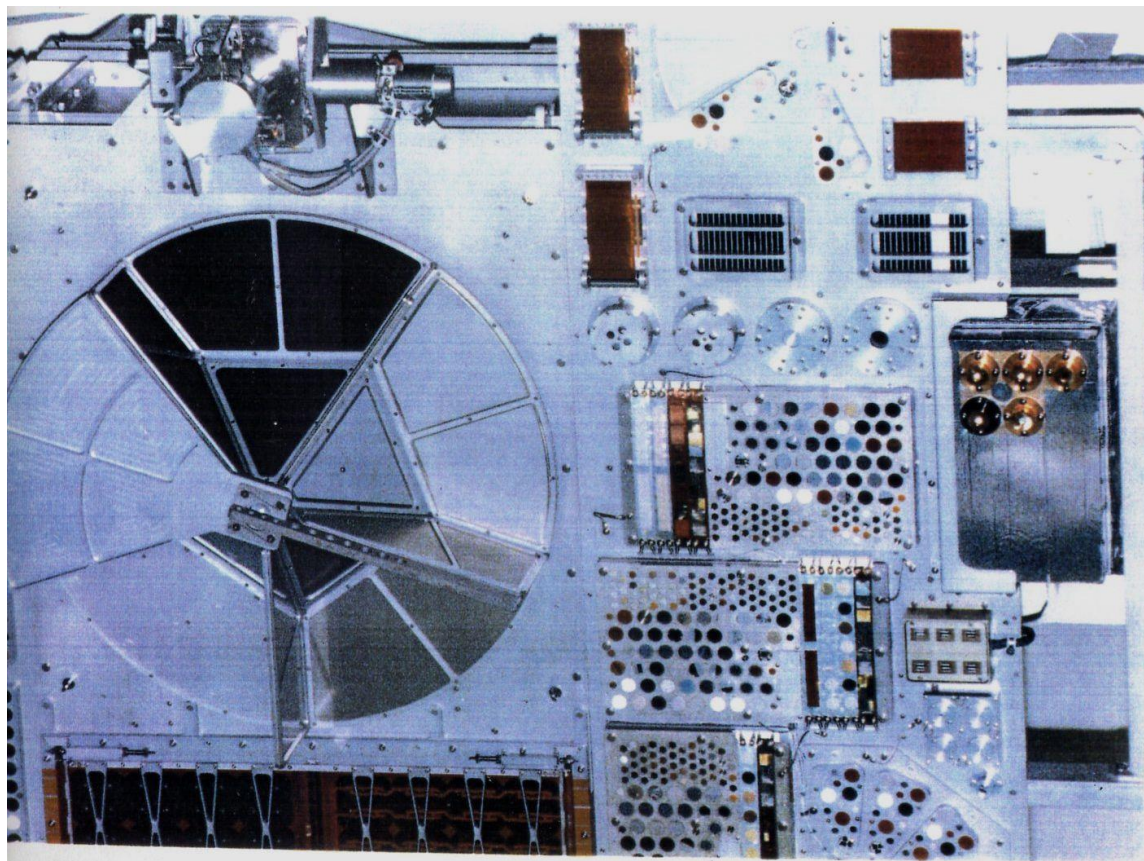
EMP PRELIMINARY RESULTS

On-Orbit Results

- Results during mission showed a significant accumulation of contaminants on all the TQCM crystals instead of expected material erosion due to atomic oxygen.
- Greatest rate of accumulation observed with shuttle bay into the ram.
- Contaminant believed to be SiO_x originating from an unknown silicone source.
- Contaminant thickness of 4205 Angstroms accreted on the uncoated TQCM through out the mission.



IN-FLIGHT AO TESTING / EIOM-3

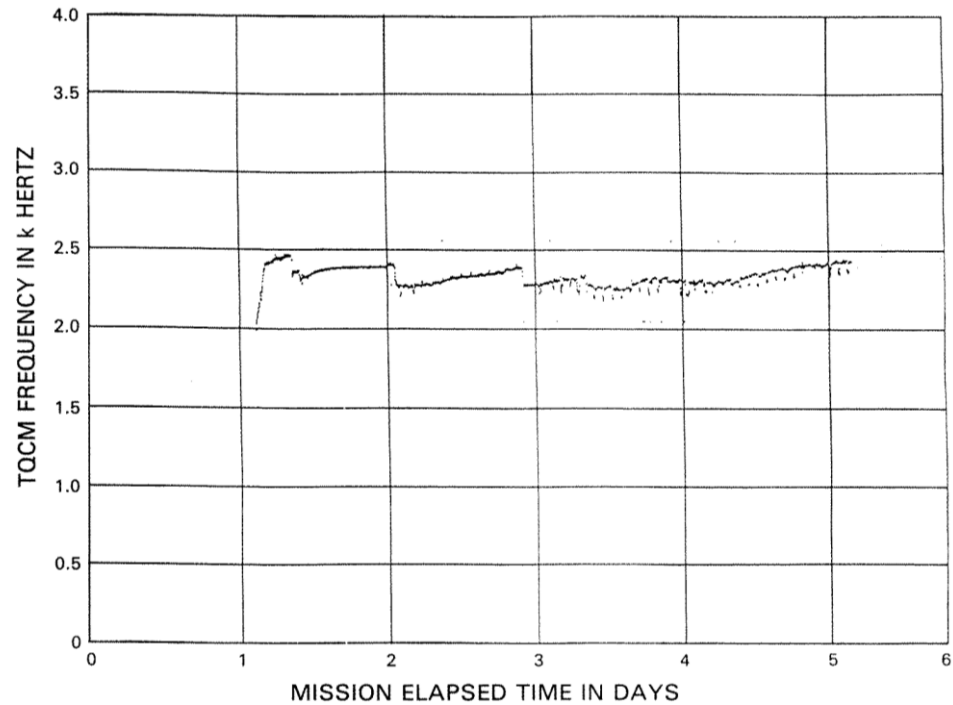




STS-8



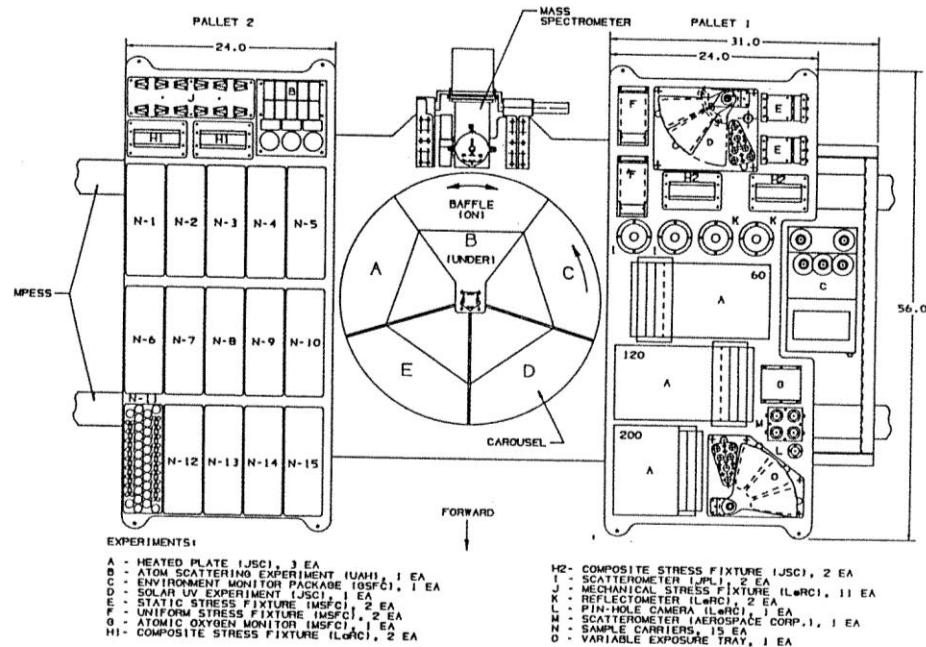
STS-8 ATOMIC OXYGEN MONITOR TQCM 3: UNCOATED (FACING OUT OF BAY)



Uncoated QCM used to detect contamination

STS-13

EOIM-3 EXPERIMENT PAYLOAD



ENVIRONMENT MONITORING PACKAGE

STS-PAYLOAD CONTAMINATION TIM

AUGUST 18, 1993

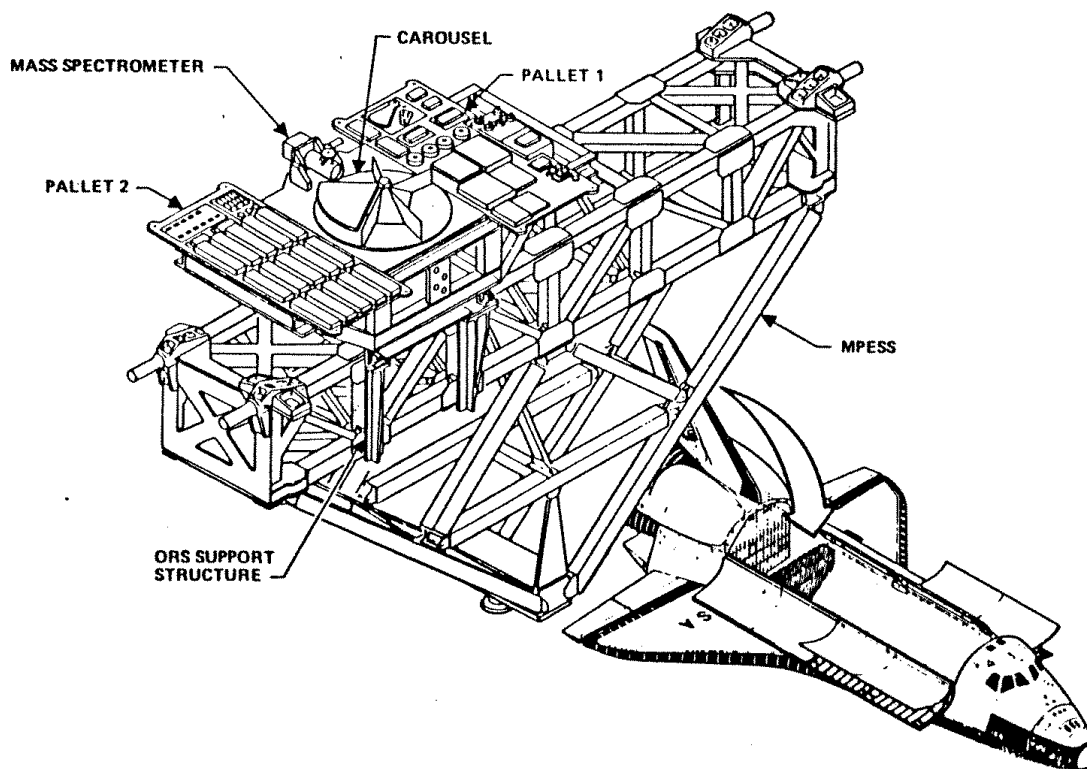
3

EMP provided real time data during flight



INFLIGHT AO TESTING STS-13

EOIM-3 EXPERIMENT PAYLOAD



EOIM 3 location in cargo bay



AO Erosion Yields for various materials

ATOMIC OXYGEN

MATERIAL	EROSION YIELD, 10^{24} CM ³ /ATOM
KAPTAN H	3.0
CHEMGLAZE Z306	0.35
FEP TEFLON	0.037-0.50
CARBON	0.9-1.7
DIAMOND	0.021
OSMIUM	0.314
SILVER	10.5
TEDLAR (CLEAR)	3.2
TEDLAR (WHITE)	0.05-0.5
EPOXY	1.7
AL/SiO ₂	0.0
GOLD	0.0
AL	0.0



Loss of Thickness Calculation

- Example: 400 km altitude, AO flux for solar max and min, Kapton surface in ram for 3 yrs
- Thickness loss/solar max
= $(5 \times 10^{14} \text{ atoms cm}^{-2} \text{sec}^{-1}) \times (3 \times 365 \times 24 \times 3600 \text{ sec}) \times (3.0 \times 10^{-24} \text{ cm}^3/\text{atom})$
= 0.14 cm (55 mils)
- Thickness loss/solar min
= $(2 \times 10^{13} \text{ atoms cm}^{-2} \text{sec}^{-1}) \times (3 \times 365 \times 24 \times 3600 \text{ sec}) \times (3.0 \times 10^{-24} \text{ cm}^3/\text{atom})$
= 0.0057 cm (2.3 mils)

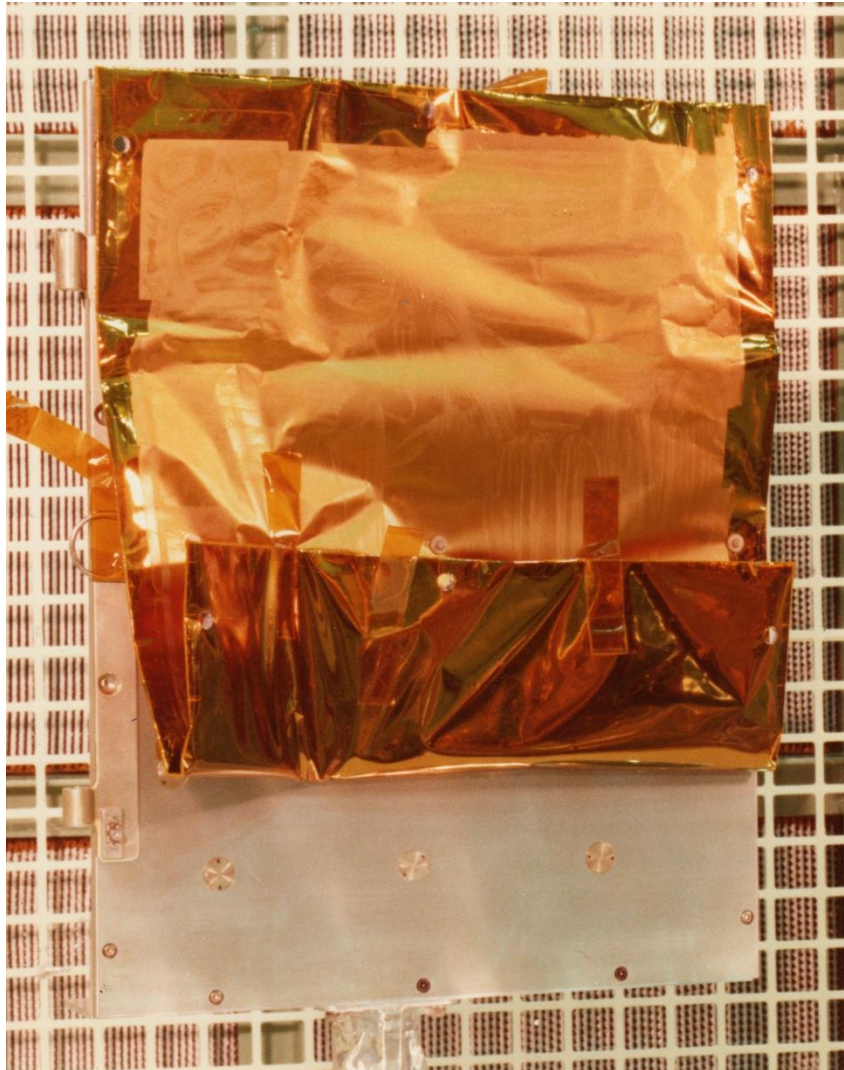


Returned Hardware





Solar Max S/C Blanket



First returned hardware from on orbit S/C.
Although looked contaminated, it tested very clean by surface analyses.



Hubble and Space Environmental Effects

(Material provided by Jackie Townsend)



**Hubble Space Telescope
Experienced Space Environmental Effects**

- The GSFC engineering team has an extensive hands-on experience in materials, coatings, contamination, and space environmental effects

HST

LDEF

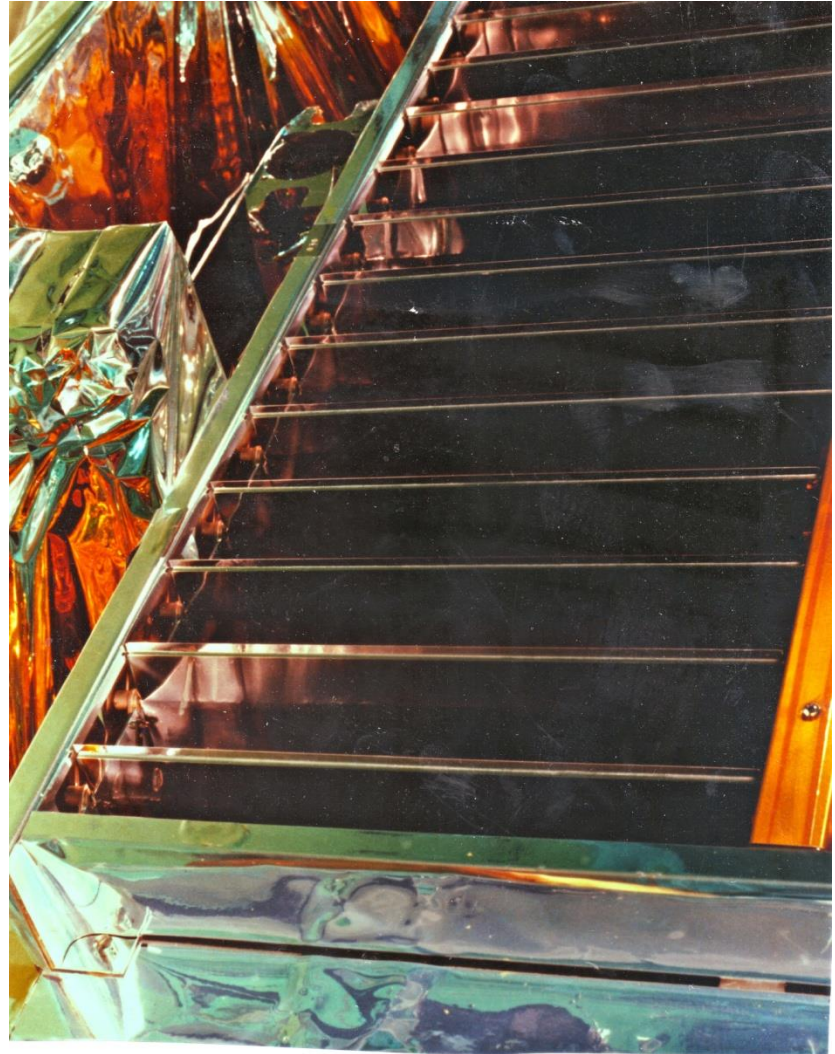
Solar Max

- Slow crack growth in polymers was experienced at levels below accepted normal damage thresholds
- Lesson learned from HST was that even when the environment is well defined, synergistic effects can still result in unforeseen degradation of materials



Solar Max Louver

Teflon tape came separated
from substrate

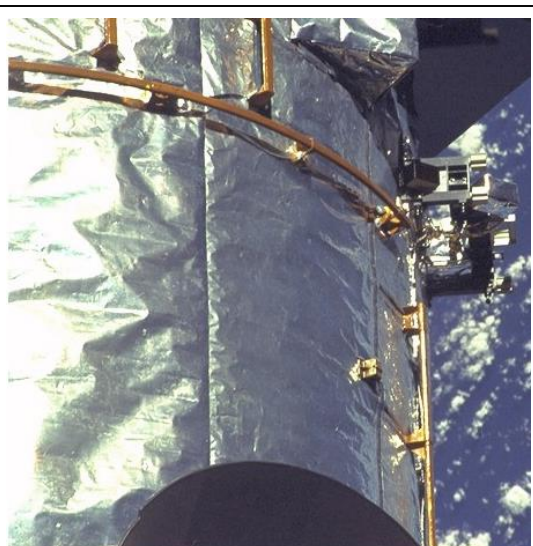




Hubble's FEP Degradation Due to Space Environmental Effects



(Material provided by Jackie Townsend.)



HST SM1: 3.6 years in LEO



HST SM2: 6.8 years in LEO

- **HST at SM2 (6.8 years in LEO)**
 - 5-mil FEP Teflon with more than 100 cracks
- **Slow Crack Growth:** Synergistic effects of radiation (electron, proton, UV, VUV) and load (internal, blanket build and assembly, thermal cycling). Evaluated temperatures accelerates degradation.



HST SM2: 6.8 years in LEO

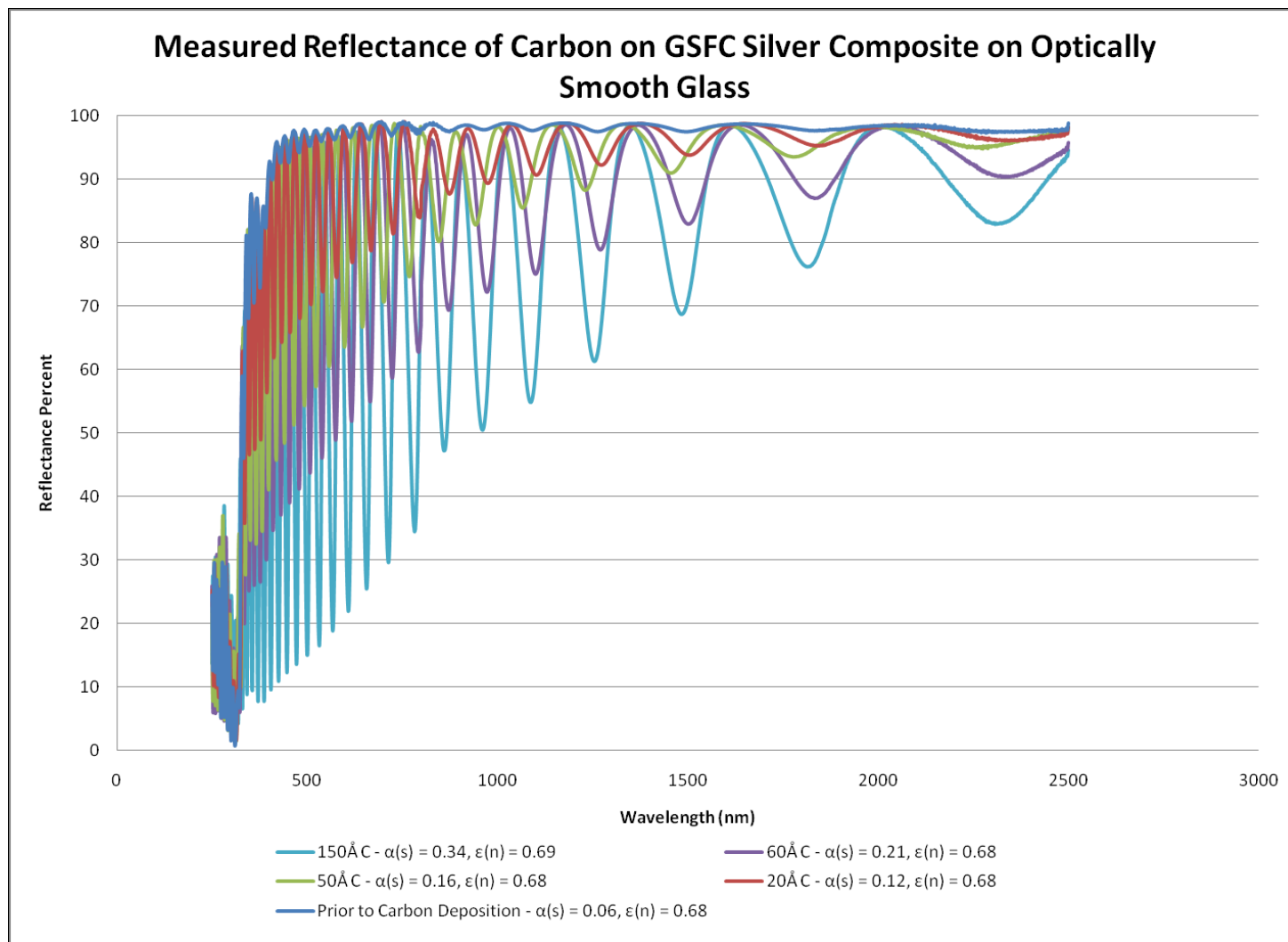


Contamination Effects

- How Does Contamination affect Coating Solar Absorptance?
 - Before on-orbit exposure? – Minor effects since hydrocarbons have low absorptance in the solar spectral region.
 - During on-orbit? – Hydrocarbons are fractured by UV and CP leaving only carbon films which adsorb heavily in the solar spectral region.
- Only carbon residues are seen on returned hardware. Silicones contaminates will also leave forms of SiO especially when AO is contained in the environment.

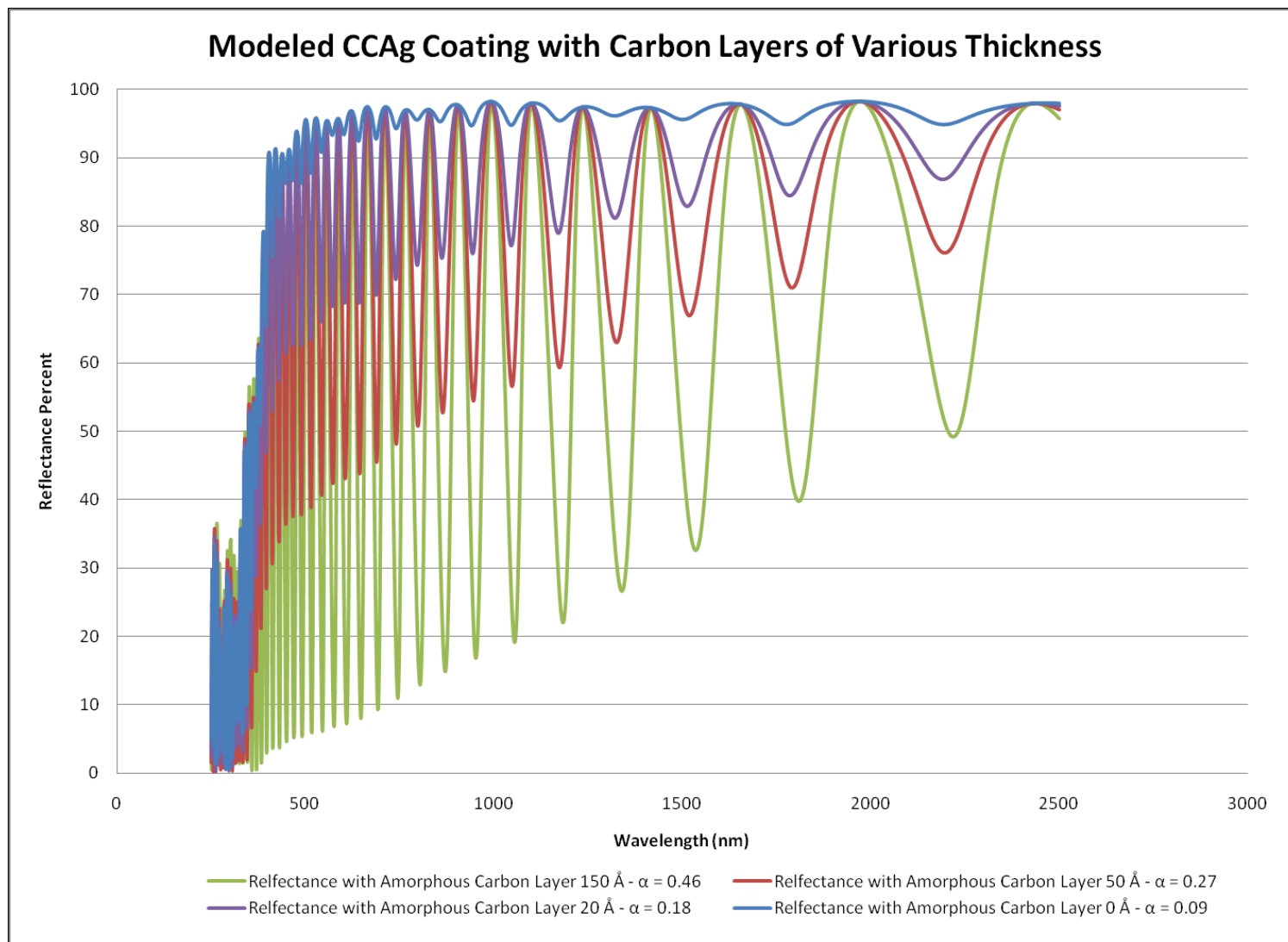


CARBON DEPOSITED ON CCAg MIRROR



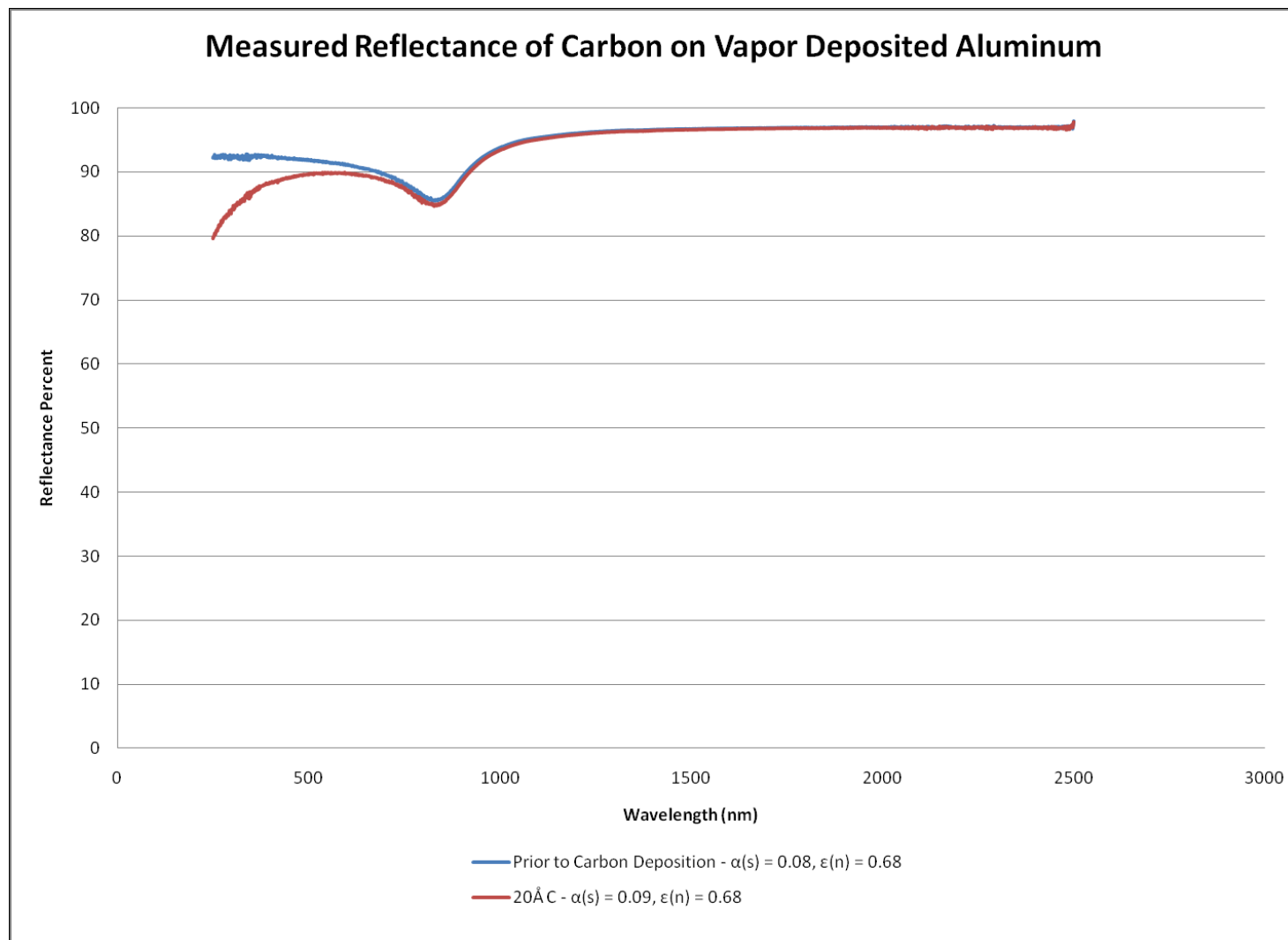


MODELED CARBON CONTAMINATION



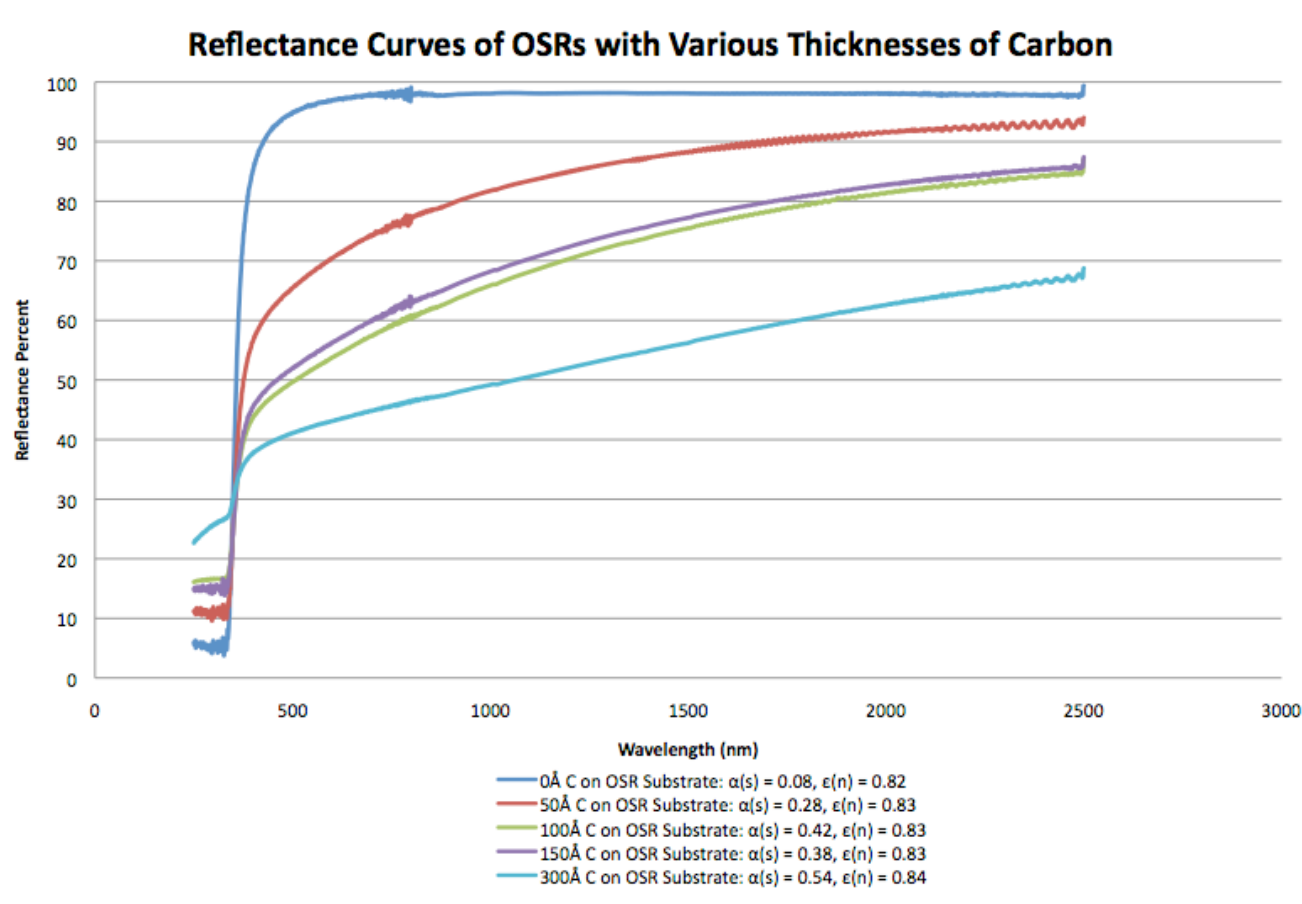


CARBON DEPOSITED ON ALUMINUM MIRROR





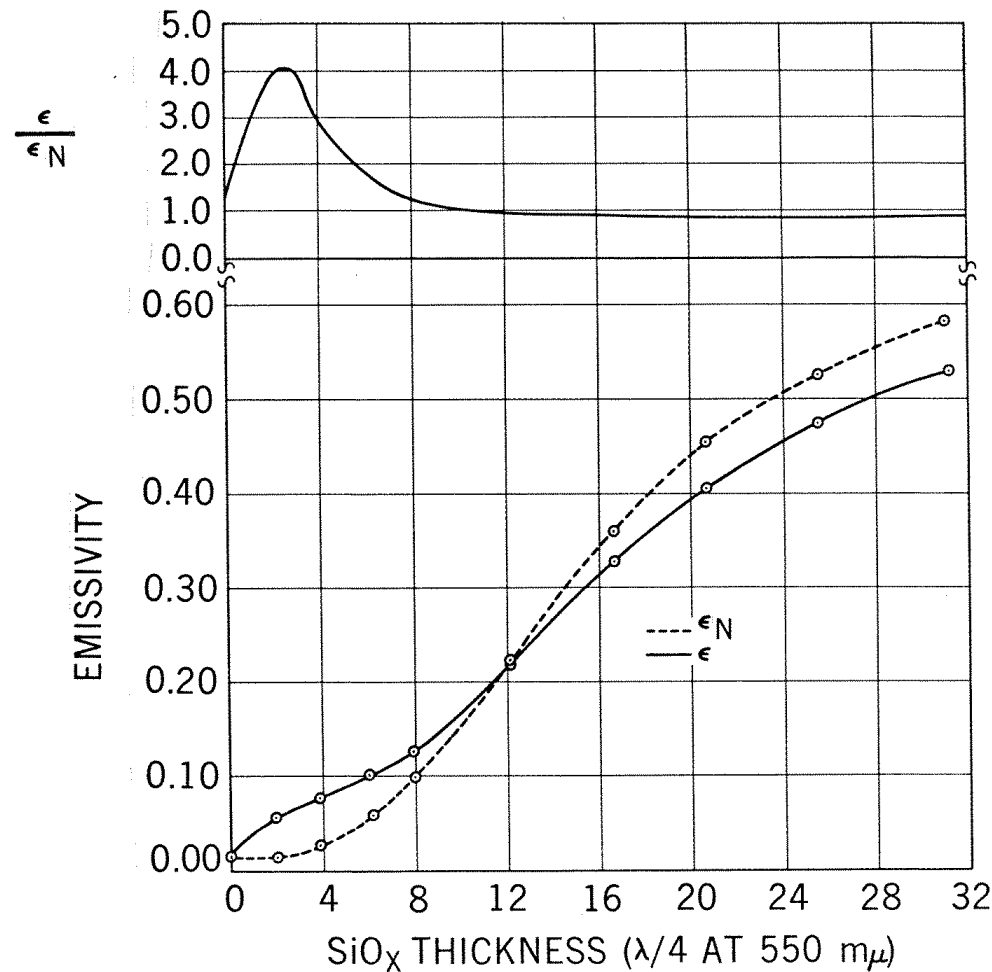
CARBON DEPOSITED ON OPTICAL SOLAR RELECTORS(OSR)



Delta absorptance same as contaminated CCAg



SiO_x /Al Emittance vs Wavelength

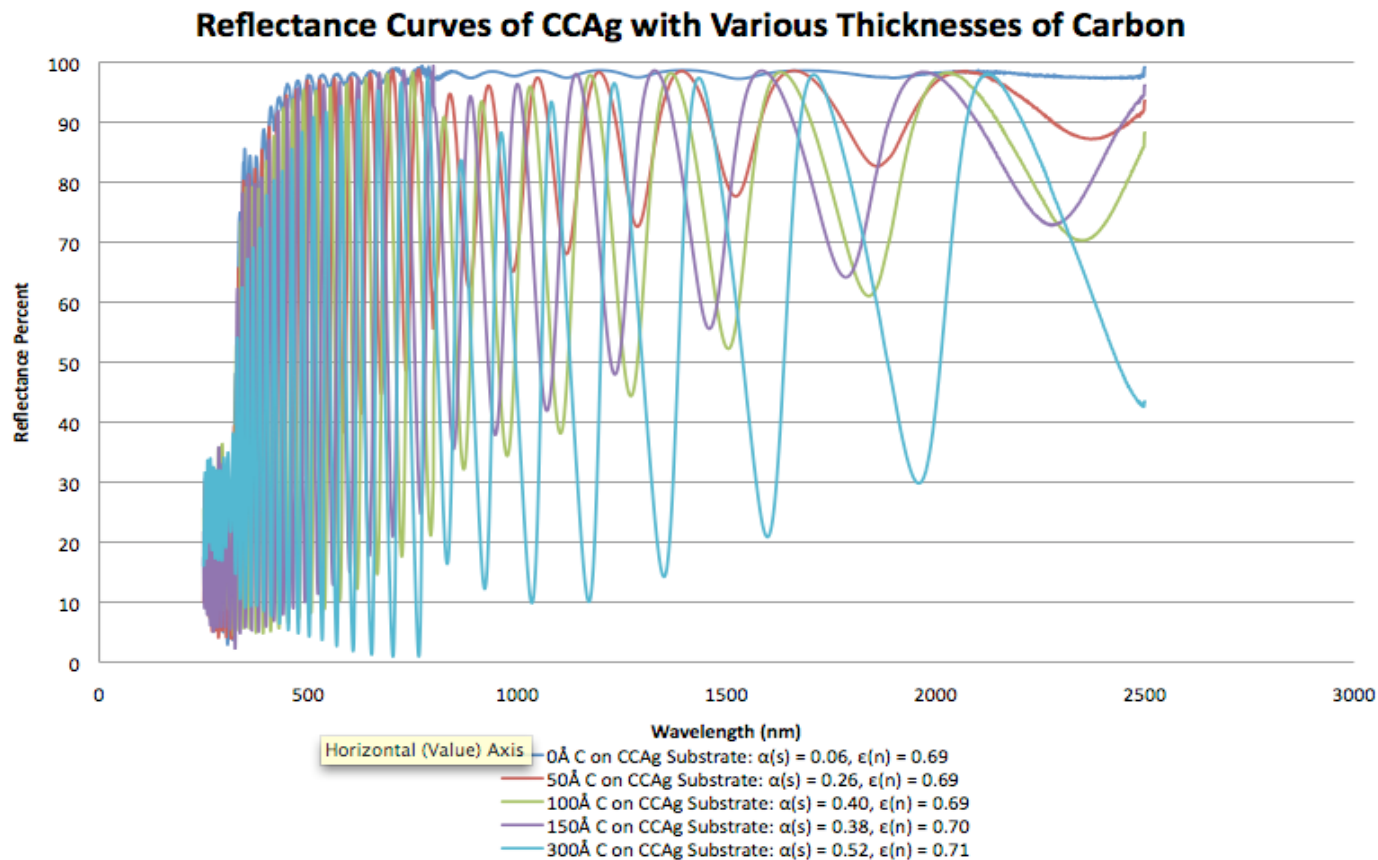


Normal emittance(ϵ_N) shows no change with deposit of the 1st quarterwave of SiO_x.

Hemispherical emittance(ϵ) shows a steady increase with SiO_x deposition.



CARBON DEPOSITED ON CCAg MIRRORS



Compare delta absorptance with OSRs

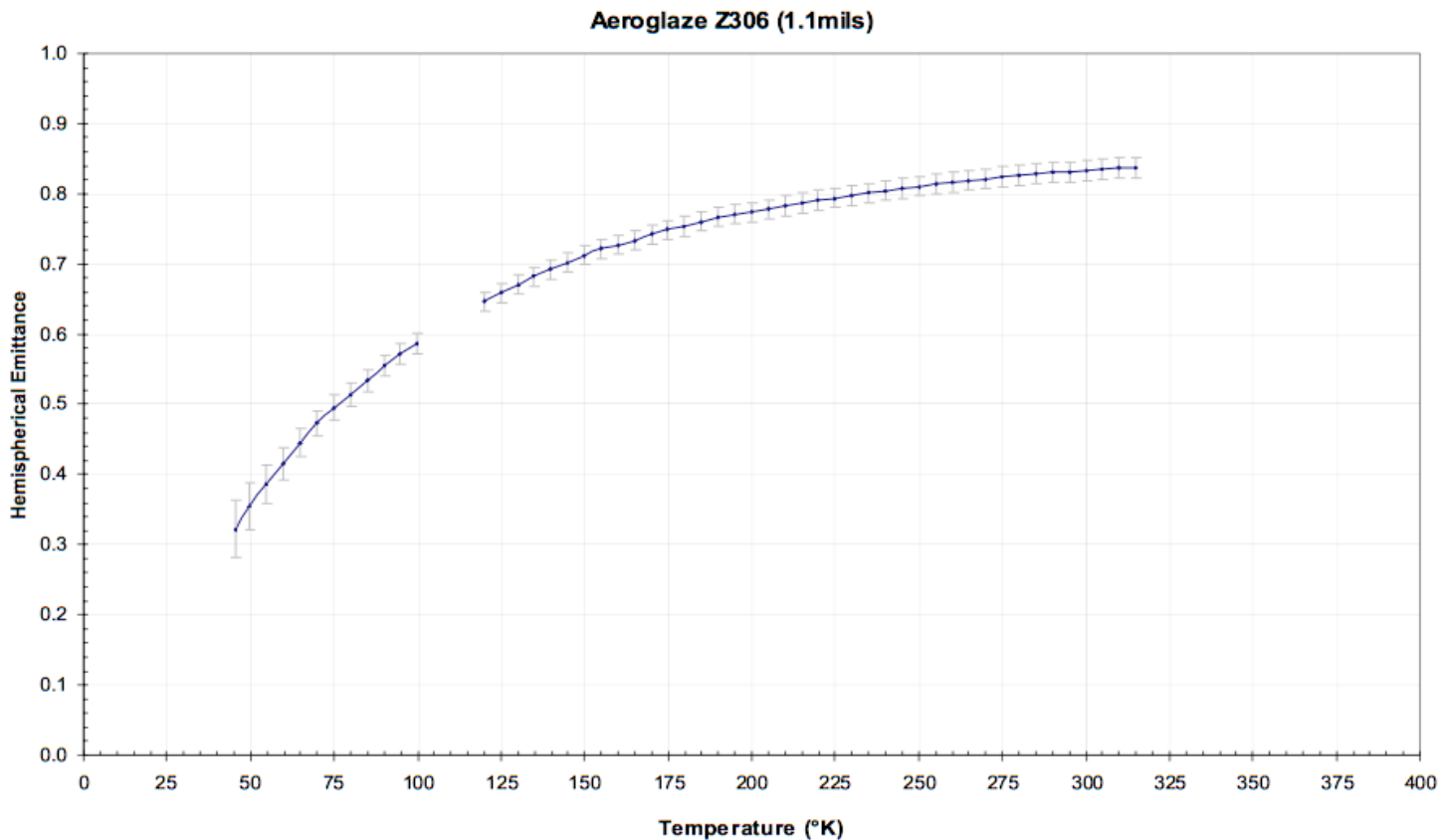


Paint Thickness Issues

- White Paint Solar Absorptance versus Coating Thickness (versus adhesion)
- Black Paint Low Temperature Emittance versus Thickness



Z306 (1.1 mils) HEMISPHERICAL EMITTANCE

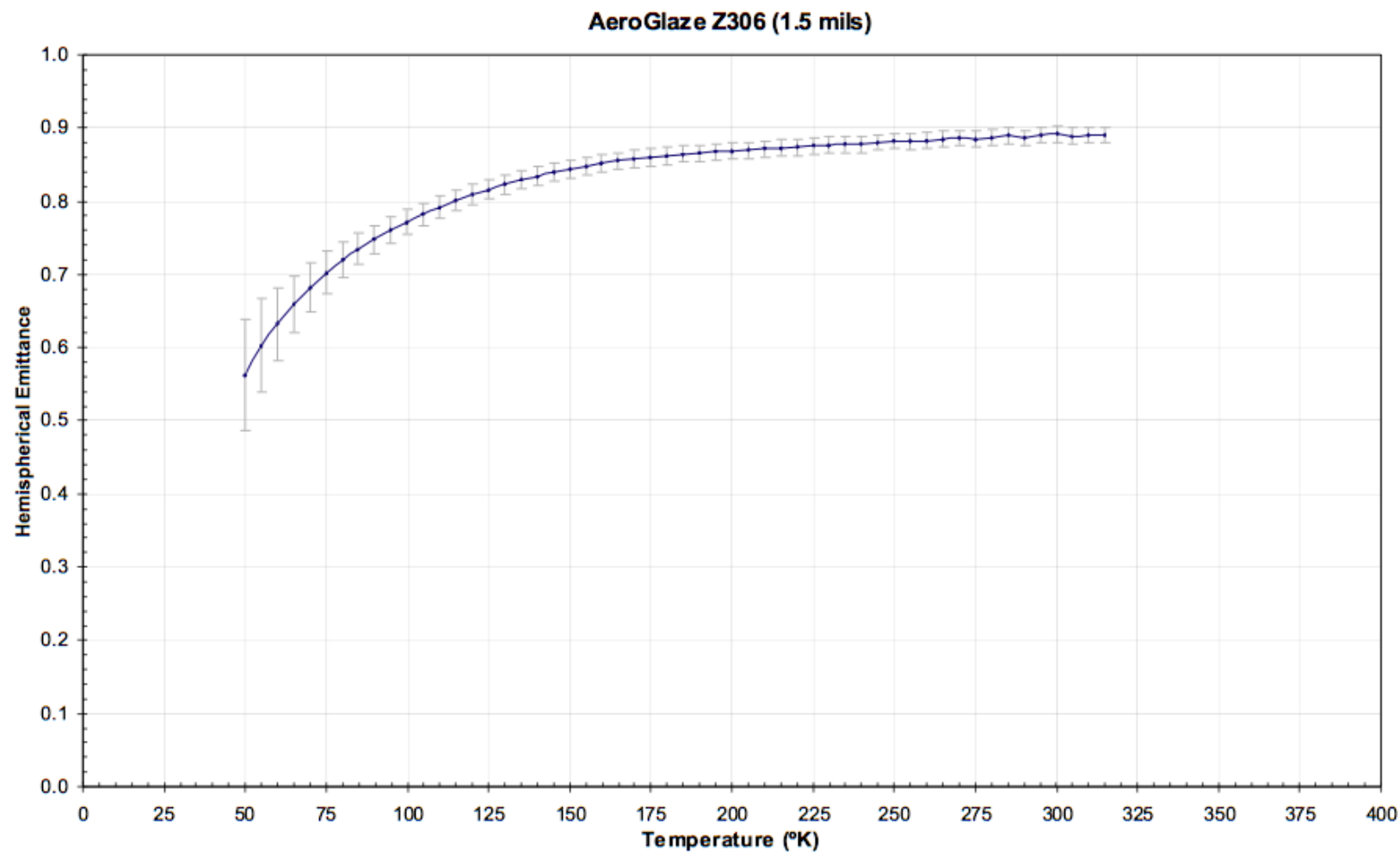


Emittance at 300K is 0.84.

Emittance at 100K is 0.58.



Z306 (1.5 mils) HEMISPHERICAL EMITTANCE





Teflon Adhesive Bleeding

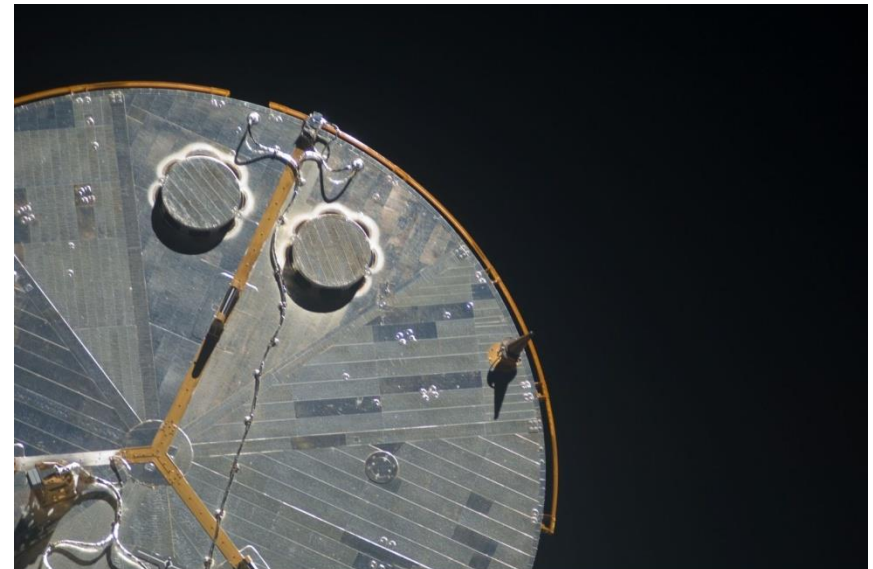
- Silver cracking during application
- Adhesive UV Degrading
- Cures



S125E006972

Note contamination darkening at vent covers

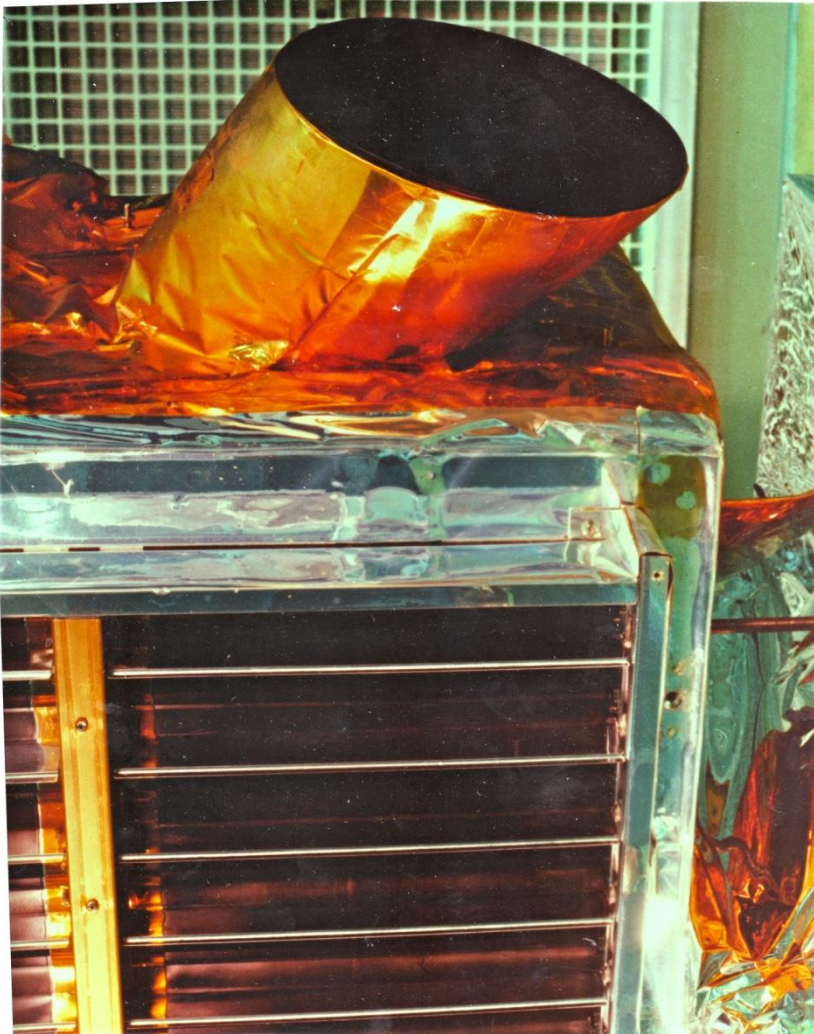
Adhesive bleeding and UV darkening



S125E006566



Solar Max Louver



Adhesive bleeding at the corner of
the louver frame